

**NASA Goddard Space Flight Center**  
**Laboratory for Extraterrestrial Physics**  
*Greenbelt, Maryland 20771*

## **1 INTRODUCTION**

The NASA Goddard Space Flight Center (GSFC) Laboratory for Extraterrestrial Physics (LEP) performs experimental and theoretical research on the heliosphere, the interstellar medium, and the magnetospheres and upper atmospheres of the planets, including Earth.

LEP space scientists investigate the structure and dynamics of the magnetospheres of the planets including Earth. Their research programs encompass the magnetic fields intrinsic to many planetary bodies as well as their charged-particle environments and plasma-wave emissions. The LEP also conducts research into the nature of planetary ionospheres and their coupling to both the upper atmospheres and their magnetospheres. Finally, the LEP carries out a broad-based research program in heliospheric physics covering the origins of the solar wind, its propagation outward through the solar system all the way to its termination where it encounters the local interstellar medium. Special emphasis is placed on the study of solar Coronal Mass Ejections (CME's), shock waves, and the structure and properties of the fast and slow solar wind.

LEP planetary scientists study the chemistry and physics of planetary stratospheres and tropospheres and of solar system bodies including meteorites, asteroids, comets, and planets. The LEP conducts a focused program in astronomy, particularly in the infrared and in short as well as very long radio wavelengths. We also perform an extensive program of laboratory research, including spectroscopy and physical chemistry related to astronomical objects.

The Laboratory proposes, develops, fabricates, and integrates experiments on Earth-orbiting, planetary, and heliospheric spacecraft to measure the characteristics of planetary atmospheres and magnetic fields, and electromagnetic fields and plasmas in space. We design and develop spectrometric instrumentation for continuum and spectral line observations in the x-ray, gamma-ray, infrared, and radio regimes; these are flown on spacecraft to study the interplanetary medium, asteroids, comets, and planets. Suborbital sounding rockets and ground-based observing platforms form an integral part of these research activities.

This report covers the period from approximately October 2001 through September 2002.

## **2 PERSONNEL**

Dr. Richard Vondrak continues as Chief of the LEP. Mr. Franklin Ottens is Assistant Chief. The Branch Heads are Dr. Joseph Nuth (Astrochemistry); Dr. Thomas Moore (Interplanetary Physics); Dr. Drake

Deming (Planetary Systems); Dr. Steven Curtis (Planetary Magnetospheres), and Dr. James Slavin (Electrodynamics). The Laboratory Senior Scientists are Drs. Richard Goldberg, Michael Mumma, Keith Ogilvie, and Louis Stief. Mr. William Mish (ISTP Deputy Project Scientist for Data Systems) is also a member of the Laboratory senior staff. The civil service scientific staff consists of Dr. Mario Acuña, Dr. John Allen, Dr. Robert Benson, Dr. Gordon Bjoraker, Dr. John Brasunas, Dr. David Buhl, Dr. Leonard Burlaga, Dr. Gordon Chin, Dr. Regina Cody, Dr. Michael Collier, Dr. John Connerney, Dr. Michael Desch, Dr. Jason Dworkin, Mr. Fred Espenak, Dr. Joseph Fainberg, Dr. Donald Fairfield, Dr. William Farrell, Dr. Richard Fitzenreiter, Dr. Michael Flasar, Dr. Mei-Ching Fok, Dr. Barbara Giles, Dr. David Glenar, Dr. Melvyn Goldstein, Dr. Natchimuthuk Gopalswamy, Dr. Joseph Grebowsky, Dr. Michael Hesse, Dr. Robert Hoffman, Dr. Donald Jennings, Mr. Michael Kaiser, Dr. John Keller, Dr. Alexander Klimas, Dr. Theodor Kostiuk, Dr. Brook Lakew, Dr. Guan Le, Dr. Ronald Lepping, Dr. Robert MacDowall, Dr. William Maguire, Dr. Marla Moore, Dr. David Nava, Dr. Walter Payne, Dr. John Pearl, Dr. Robert Pfaff, Dr. Dennis Reuter, Dr. D. Aaron Roberts, Dr. Paul Romani, Dr. Robert Samuelson, Dr. David Sibeck, Dr. Amy Simon-Miller, Dr. Edward Sittler, Dr. Michael Smith, Dr. David Stern, Dr. Adam Szabo, Dr. Jacob Trombka, Dr. Adolfo Figueroa-Viñas, and Dr. Peter Wasilewski. Also Co-op Graduate students, Mr. Daniel Martinez, Ms. Kelly Fast, Mr. Walter Allen, and Ms. Lucy Lim. The Laboratory also has a large scientific staff who are not Civil Servants. The following are National Research Council Associates (NRC): Dr. Robert Boyle, Dr. Stephen Christon, Dr. John Dorelli, Dr. Roberto Fernandez-Borda, Dr. Erika Gibb, Dr. Jesper Gjerloev, Dr. Cedric Goukenleuque, Dr. Hugh Hill, Dr. Kristi Keller, Dr. Hina Khan, Dr. Gunther Kletetschka, Dr. Alexander Kutepov, Dr. Jan Merka, Dr. Therese Moretto, Dr. André Pimentel, Dr. Frank Schmülling, Dr. Kristine Sigsbee, Dr. Christian Steigies, Dr. Eija Takanen, Dr. Vadim Uritsky, Dr. Arcadi Usmanov, Dr. Oleg Vaisberg, Dr. Phillip Webb, Dr. Robert Weigel, and Dr. Michael Wong. The following scientists work at the LEP as either contractors to GSFC or as long-term visiting faculty: (L3EER) Dr. Daniel Berdichevsky, Dr. Henry Freudenreich, Dr. Sanjoy Ghosh, Dr. Roger Hess, Dr. Vladimir Osherovich, Dr. Pamela Solomon, and Dr. Adinarayan Sundaram; (Raytheon/ITSS) Dr. Ashraf Ali, Dr. Rainer Fettig, Dr. Venku Jayanti, Dr. Maria Kuznetsova, and Dr. Lutz Rastätter; (Universities Space Research Association (USRA)) Dr. Sheng-Hsien Cheng, Dr. Satoshi

Taguchi, Dr. Nikolai Tsyganenko, Dr. Dimitris Vasiliadis, and Dr. Yihua Zheng; (Computer Sciences Corporation (CSC)) Dr. Larry Evans; (Catholic University of America) Dr. Pamela Clark, Dr. Dana Crider, Dr. Tamara Dickinson, Dr. Michael DiSanti, Dr. Frank Ferguson, Dr. Patrick Michael, Mr. George McCabe, Dr. Robert Nelson, Dr. Fred Nesbitt, Dr. Michael Reiner, Dr. Neil Dello Russo, and Dr. Richard Starr; (Space Science Applications, Inc. (SSAI)) Dr. Richard Achterberg, Dr. Ronald Carlson, and Dr. Mauricio Peredo; (University of Maryland Baltimore County (UMBC)) Dr. David Steyert; (University of Maryland, College Park) Dr. Dennis Chornay, Dr. Thejappa Golla, Dr. Tilak Hewagama, Dr. John Hillman, and Mr. Virgil Kunde; (Charles County Community College) Dr. George Kraus; (IONA College) Dr. Robert Novak; (Cornell University) Dr. Barney Conrath and Dr. Paul Schinder; (Challenger Center) Dr. Jeff Goldstein and Dr. Timothy Livengood; (NOMAD Research) Dr. Dean Pesnell; (John's Hopkins Applied Physics Laboratory (APL/IPA)) Dr. Nicola Fox; (Eckerd College) Dr. Reginald Hudson; (University of Colorado) Mr. Jeremy Richardson; (University of Alabama) Dr. Chin-Chun Wu; (University of Tennessee) Dr. William Blass; (University of Oslo) Dr. Nikolai Ostgaard.

A small and very capable staff of engineers, technicians, secretaries, and computational personnel also support the work of the LEP scientists.

### 3 ASTROCHEMISTRY

#### 3.1 Cosmic Ices

Near and mid-infrared spectra of energetically processed cosmic-type ices reveal a variety of physical-chemical and radiation chemical changes including the formation of new molecules. Results are applied to current problems in astrochemistry such as the formation and evolution of cometary and interstellar molecules containing H, C, N, and O. Results applied to studies of the icy Galilean satellites focus on the formation and evolution of sulfur-containing molecules. New results from the Cosmic Ice Laboratory led by M. Moore include:

*Different Radiation Products Found in N<sub>2</sub> Ices-UV Photolysis vs. Ion-bombardment.* Distinguishing between astronomical ices that have been UV-photolyzed or those that have been ion-irradiated has been a long-standing problem. Their experiments on solid N<sub>2</sub> and N<sub>2</sub>-rich ices reveal that the nitrogen radical, N<sub>3</sub>, is easily detected by infrared spectroscopy after ion irradiation. In contrast, no N<sub>3</sub> is found after UV photolysis. This N<sub>3</sub> absorption feature might be used as a tracer of ion processing in cold N<sub>2</sub>-rich ices.

*HCN and HNC Formation and Stability in N<sub>2</sub>-rich Ices Relevant to Triton and Pluto.* N<sub>2</sub>-rich ices containing small amounts of CO, and CH<sub>4</sub> dominate the surfaces of both Pluto and Triton. In addition these ices are exposed to ionizing radiation in the form of cosmic rays. Completed laboratory work shows that similar ices irradiated with MeV protons contain HCN and HNC in

about equal abundance along with CH<sub>2</sub>N<sub>2</sub>, NH<sub>3</sub>, and HNCO. It was also found that warming these irradiated ices produces the NH<sub>4</sub><sup>+</sup>, CN<sup>-</sup> and OCN<sup>-</sup> ions, all candidates for detection by future IR missions.

*IR Spectra of Ion-irradiated Ices Containing SO<sub>2</sub>.* Spectra of Europa reveal a surface dominated by water-ice along with hydrated materials and minor amounts of SO<sub>2</sub>, CO<sub>2</sub>, and H<sub>2</sub>O<sub>2</sub>. The surface is under intense bombardment by the Jovian magnetospheric radiation, which can alter the surface composition through radiolysis and ion implantation. In order to understand the radiation induced changes in Europa-like ices, the Cosmic Ice Laboratory measured the mid-IR spectrum of proton irradiated H<sub>2</sub>O ice containing SO<sub>2</sub>. Ices with H<sub>2</sub>O/SO<sub>2</sub> ratios of 3 and 30 have been completed at 86 K, 110 K and 132 K. Several new products are identified including the sulfate ion.

### 4 PLANETARY SCIENCE

#### 4.1 Laboratory Studies

##### *Kinetics - Outer Planet Hydrocarbon Chemistry.*

With the recent detection of the methyl radical in the atmospheres of Jupiter, Saturn, and Neptune it has been observed that the column densities of CH<sub>3</sub> for Saturn and Neptune are lower than those calculated from atmospheric photochemical models. The major sink for methyl radicals is the self-reaction CH<sub>3</sub> + CH<sub>3</sub> + M → C<sub>2</sub>H<sub>6</sub> + M. If the rate constant for this reaction at the low temperatures and pressures of the atmospheres of these outer planets is significantly greater than that estimated from measurements in the laboratory at higher temperatures and pressures, then a larger value of the rate constant would resolve the discrepancy between observed and calculated CH<sub>3</sub> column densities. This discrepancy prompted recently published discharge-flow mass spectrometric measurements of the rate constant for the self-reaction at 298 and 202 K. These were the first measurements at temperatures below T = 298, K. R. Cody, L. Stief, F. Nesbitt (Coppin State College), P. Romani, D. Tardy, (University of Iowa) M. Iannone (Millersville University) have now been motivated to extend the measurements to 155 K which is a more appropriate temperature for the planets. The measured rate constant is very close to the high-pressure limit. Their results indicate that while the newly measured rate constant makes the self-reaction fast enough to explain the Neptune data, there is still a problem reconciling models with the observed Saturn data. This indicates the presence of an additional problem in the photochemical models of Saturn.

In the laboratory study of the CH<sub>3</sub> self-reaction described above, the source of the methyl radical was the reaction F + CH<sub>4</sub> → CH<sub>3</sub> + HF. It is, therefore, important in these types of experiments to know the initial fluorine concentration, which is generally obtained using the titration reaction F + Cl<sub>2</sub> → Cl + FCl. Knowledge of the rate constant and temperature dependence for the titration reaction was scarce and no measurements are

available for  $T < 298$  K. Therefore, R. Cody, F. Nesbitt, and D.A. Dalton, (Lynchburg College) have collaborated with colleagues at CNRS, Orleans, France, to measure this rate constant. The combined results give a value of  $k(\text{F} + \text{Cl}_2) = (6.1 \pm 1.1) \times 10^{-11} \text{ cm}^3 \text{ molecule}^{-1} \text{ s}^{-1}$ . The reaction rate constant does not show a temperature dependence.

*Kinetics - Earth's Upper Atmosphere.* In the stratosphere, loss processes of chlorine atoms can disrupt the chlorine atom catalyzed destruction of ozone. The major process which converts active Cl to the inactive HCl reservoir is the reaction (1)  $\text{Cl} + \text{CH}_4 \rightarrow \text{CH}_3\text{Cl} + \text{HCl}$ . Two recent studies have raised the possibility that the atom radical reaction of Cl with  $\text{CH}_3$  may have contributed to the observed loss of Cl in laboratory measurements of the rate constant for reaction (1). In order to evaluate this possibility and thereby make corrections to the extent to which previous measurements of the rate constant may have been compromised, L. Stief, R. Cody, W. Payne, J. Parker (Catholic University of America), and F. Nesbitt have initiated a discharge flow-mass spectrometric study of the reaction (2)  $\text{Cl} + \text{CH}_3 + \text{M} \rightarrow \text{CH}_3\text{Cl} + \text{M}$  at low temperatures and pressures. The only data available in the literature for this reaction is derived from a complex system of reactions involving the photochlorination of methane at temperatures of 298-423 K and pressures of 50-300 Torr of  $\text{CO}_2$  as the major gas. The high-pressure value of the measured rate constant as reported in the literature, has been used to correct the  $\text{Cl} + \text{CH}_4$  experiments performed at low pressures. In general, it is not desirable to use data extrapolated from higher pressures or temperatures to correct experimental data obtained at lower temperatures and pressures. The current study represents the first direct, absolute measurement of the rate constant for reaction (2) and will supply a data base that is more suitable for use in correcting the low pressure and low temperature data derived from the previous experiments for reaction (1). In this study,  $k_2$  has been measured between 0.5 and 2 Torr (He) and temperatures of 298, 250, and 202 K respectively. As expected,  $k_2$  increases with pressure at all three temperatures with increases of 75%, 50%, and 35% being observed for 298, 250, and 202 K respectively. At any one pressure, increases in  $k$  of a factor of 2-3 are observed as the temperature decreases. The range of values for  $k_2$  measured in this study for 200-250 K and 1 Torr (He) are 10-20 times smaller than those used to correct the laboratory  $\text{Cl} + \text{CH}_4$  measurements at these temperatures and pressures.

P. Romani collaborated with R. Cody, L. Stief, F. Nesbitt, M. Iannone, and D. Tardy on the interpretation of laboratory measurements of the methyl recombination rate. Recent observations of methyl in the stratospheres of Neptune and Saturn indicated that standard photochemical models were predicting too high of a methyl column. Since the model-observation comparison can be used to derive the strength of vertical mixing in the stratospheres of these planets this had implications for understanding the atmospheric dynamics of these plan-

ets. The first measurements of this rate constant at low pressure and temperature were then made at Goddard. These laboratory measurements were then used to construct analytical expressions for the rate constant of use for photochemical models. Preliminary results indicate that for the models to agree with the whole suite of observations of hydrocarbons on these planets another methyl sink and/or a reduced methyl production rate must be used.

## 4.2 Gas-Phase Spectroscopy

*High-resolution Laboratory Infrared Spectroscopy of Gaseous Molecular Species.* Research by the LEP spectroscopy group focuses primarily on molecules of planetary and astrophysical interest, and supports NASA flight missions in both these areas. The work also supports ground-based astronomy and terrestrial atmospheric studies. Particular emphasis is placed on obtaining reliable intensities, self- and foreign-gas pressure broadening coefficients, line-mixing effects and temperature dependent spectra. There is a vigorous program to measure Tunable Diode Laser (TDL) and Fourier Transform Spectrometer (FTS) spectra at wavelengths greater than 10  $\mu\text{m}$ . Supporting laboratory measurements are scarce for these wavelengths, but are crucial for the analysis of data from upcoming space missions such as Cassini, where the Composite Infrared Spectrometer (CIRS) will obtain spectra of Saturn and Titan from 7 to 1000  $\mu\text{m}$ . Recent activities of the group have included obtaining and/or analyzing spectral data for excited state and fundamental transitions in  $\text{H}_2$ ,  $\text{H}_2\text{O}$ ,  $^{13}\text{C}^{12}\text{CH}_6$ ,  $^{12}\text{C}_2\text{H}_6$ ,  $\text{C}_2\text{H}_4$ ,  $\text{C}_2\text{H}_2$ ,  $\text{N}_2\text{O}$ ,  $\text{CO}_2$ ,  $\text{C}_3\text{H}_4$  (both the methylacetylene and allene isomers),  $(\text{CH}_3)_2\text{CO}$  and  $\text{HNO}_3$ . This work has been carried out in collaboration with personnel at several institutions including W.E. Blass (University of Tennessee), N.M. Donahue (Harvard University), J.M. Frye (Howard University), J.W.C. Johns (NRC, Canada), A. Perrin (C.N.R.S., Paris), M. Sirota, L.L. Strow and W. Wang (UMBC), C.B. Suarez (NRC, Argentina) and R.H. Tipping (University of Alabama). These measurements have already impacted planetary studies. For example, the  $\nu_{12}$   $^{13}\text{C}$  ethane ( $^{13}\text{C}^{12}\text{CH}_6$ ) intensities have been used in conjunction with ground-based observations to infer an essentially terrestrial  $^{13}\text{C}/^{12}\text{C}$  ratio on Jupiter and Saturn. The intensities of the ethylene ( $\text{C}_2\text{H}_4$ ) transitions have been used to obtain this species concentrations in the upper atmosphere of Saturn. The low temperature line intensity and self- and nitrogen broadened measurements of the  $\nu_9$  band of allene near 28  $\mu\text{m}$  are the first such measurements of this band, and are among the longest wavelength TDL data ever obtained. The high-pressure long-pathlength  $\text{CO}_2$  broadening spectra show the clear effects of line-mixing and far-wing line shapes in this species and may be used to model atmospheric spectra for the Mars Global Surveyor mission. The parameters obtained from these experiments are crucial to the proper interpretation of the upcoming CIRS measurements of the atmosphere of Titan.

As well as obtaining and analyzing spectra, the group places a strong emphasis on improving instrumentation and, among other accomplishments, has developed a unique TDL system for obtaining spectra to  $\sim 30\ \mu\text{m}$  employing advanced (Si:As and Si:Sb) detectors, high performance lead-salt lasers and a long-path White-type sample cell. A very long-path, coolable White-type cell has been assembled which allows pathlengths in excess of 500 m at temperatures as low as 150 K. They have also obtained a CsI beamsplitter which has been used to expand the long-wavelength capability of the Bruker FTS spectrometer at the atmospheric chemistry group at Harvard University, which they use in collaborative spectroscopy experiments.

## 5 PLANETARY OBSERVATIONS

### 5.1 Mercury

*Polarization of the Sodium D Lines in Mercury's Exosphere.* High-resolution spectropolarimetric images were obtained using a polarization package with the Fabry-Perot interferometer on the Dunn Solar Telescope at Sac Peak, New Mexico, by J. Allen, M. Penn (NSO), B. Michael, and D. Branstor. Subsequent high-resolution spectropolarimetry taken with a polarization package and the Solar Stellar Spectrograph on the McMath/Pierce Telescope at Kitt Peak, AZ confirmed the imaging results obtained at Sac Peak. Initial analysis of the data has been performed and the results are being prepared for publication.

### 5.2 Earth

*Atmospheric Absorption of Solar Radiation.* A new instrument has been developed to provide data on various absorbers and absorption processes in the Earth's atmosphere: trace-gases, clear-sky absorption, aerosols, subvisual cirrus. It is based on two circular variable filters covering wavelengths from 450 nm to  $1.2\ \mu\text{m}$  and  $1.2$  to  $4.5\ \mu\text{m}$ . There is a slight overlap at  $1.2\ \mu\text{m}$  and the two filters are run simultaneously, so the entire spectral region from 450 nm to  $4.5\ \mu\text{m}$  is covered continuously. The low-resolution instrument tracks the Sun and therefore can most succinctly be described as a tunable sun photometer. The instrument can be absolutely calibrated in the laboratory and has recently been tested at GSFC's Geophysical and Astronomical Observatory. It is currently being prepared for deployment in the field at various sites around the country.

### 5.3 Mars

*Martian Volatiles.* Martian clouds and surface volatiles are being investigated by D. Glenar with Co-investigators G. Bjoraker, R. Samuelson, and D. Blaney (JPL) using ground-based IR mapping data which spans multiple Mars apparitions. The properties and diurnal behavior of Martian aphelion season clouds have been studied using data acquired by the KPNO Cryogenic Spectrometer during the '99 opposition ( $L_s=130^\circ$ ). Results show the diurnal evolution of discrete topo-

graphically related water ice clouds and features in the diffuse seasonal cloud band, both of which were mapped during the same season by Mars Global Surveyor (MGS)/Thermal Emission Spectrometer (TES) at fixed (1400 hrs) local time. Comparisons of scattering models with the cloud spectral shapes show the spatial distribution of cloud  $3\ \mu\text{m}$  opacity and ice aerosol content. Spectral maps of Mars in K and L bands were also acquired using the NASA InfraRed Telescope Facility (IRTF) SpeX during June and July '01 ( $L_s=185^\circ$ - $195^\circ$ ). These observations bracket the onset of the early season dust storm, monitored by MGS/TES (M. Smith, J. Pearl). Reconstructed image cubes ( $x$ - $y$ - $\lambda$ ) are being used to generate maps showing the spatial distribution of polar region ices.

*Mars Global Surveyor Thermal Emission Spectrometer (MGS/TES).* Atmospheric investigations of Mars by the GSFC group of the MGS/TES experiment team continued. Nearly two Martian years of infrared spectral data have been obtained from the MGS mapping orbit. These data are being used to study interannual variations in atmospheric phenomena by M.D. Smith.

MGS/TES limb infrared spectra are being used to study the non-LTE (Local Thermodynamic Equilibrium)  $\text{CO}_2$  hot band emission observed in Mars' middle atmosphere. The global dust storm which began in late June 2001 presents an opportunity to study its effect on this  $10\ \mu\text{m}$   $\text{CO}_2$  emission. Comparison of MGS/TES observations of the corresponding previous Martian year ( $L_s=200$ - $220$ ) shows the emission region is elevated by about  $10\ \text{km}$  higher than the region during low dust conditions.

M.D. Smith has been using MGS/TES infrared spectra to monitor the seasonal and spatial distribution of aerosols and water vapor. There are now nearly two full Martian years of data from MGS. In the past year, M. Smith has documented the initiation, growth, and decay of a planet-encircling dust storm and has begun to examine the amount of interannual variability between results from the first Martian year of MGS mapping and the present (second) year. M. Smith has also used TES limb-geometry spectra to study the scattering properties and the vertical distribution of dust and water-ice aerosols and water vapor gas.

*Mars Odyssey Thermal Emission Imaging System (THEMIS).* M.D. Smith was selected as a Participating Scientist for the Mars Odyssey mission. He has been using THEMIS thermal infrared data to retrieve atmospheric temperatures, and the amount of dust and water ice aerosol. Odyssey's orbit is at a different local time than MGS and provides atmospheric information complementary to that of MGS TES.

*Stability of Mars  $\text{CO}_2$  Atmosphere - Seasonal Variability of Ozone.* K. Fast, a co-op student, is continuing her work on the application of heterodyne measurements of ozone to the Martian  $\text{CO}_2$  stability problem. Ozone is an important tracer of the  $\text{CO}_2$  reformation process on Mars involving products of water photolysis. Infrared absorption lines of ozone from heterodyne spectra taken during many different Martian seasons are being ana-

lyzed to investigate ozone and water anti-correlations and to compare with CO<sub>2</sub> reformation models. Additional measurements with the Heterodyne Instrument for Planetary Wind and Composition (HIPWAC) are planned during 2003 with advisor T. Kostiuk, T. Livengood, T. Hewagama, and F. Espenak.

*Physics of Mars Non-LTE CO<sub>2</sub> Emission.* T. Kostiuk with Co-investigators T. Livengood, W. Maguire, J. Pearl, F. Espenak, and T. Hewagama are supporting MGS/TES observations that have detected and spatially mapped non-thermal emission by CO<sub>2</sub> in the upper atmosphere of Mars. TES observations lack the requisite spectral resolution to resolve the individual emission lines and thereby derive physical information about the source region. HIPWAC observations conducted in August 2001 sensed non-LTE ro-vibrational lines of CO<sub>2</sub> with sufficient signal-to-noise to characterize the gas kinetic temperature in the source region from the Doppler line broadening. Observations were conducted along the ~2 PM dayside track (45S to 60N degrees latitudes) of the MGS at high resolution,  $\lambda/\delta\lambda=5\times10^6$ . Retrieved mesospheric temperatures ranged from 130K to 190K. A serendipitous bonus from these measurements was the observation of variable depth in the pressure-broadened CO<sub>2</sub> absorption profile at disc center due to the global dust storm in progress at the time, providing a gauge of the altitude to which dust was circulated. Initial results from this observing program were reported at the 2001 DPS Meeting.

*Ground-based Mapping of Ozone and Water on Mars.* M.J. Mumma, R. Novak, M.A. DiSanti, N. Dello Russo, and K. Magee-Sauer (Rowan University) published the first quantitative maps of ozone and water on Mars, based on a new approach for remotely sensing these photochemically-linked species from ground-based observatories. The season on Mars was late northern spring ( $L_s = 67.3^\circ$ , UT January 21.6 1997). Absolute abundances of O<sub>3</sub> and H<sub>2</sub>O along the central meridian were obtained from long-slit maps of O<sub>2</sub> ( $a^1\Delta_g$ ) and HDO, acquired with the high-resolution infrared spectrometer, Cryogenic Echelle (CSHELL) at the NASA IRTF. O<sub>2</sub> ( $a^1\Delta_g$ ) is produced by ozone photolysis, and the ensuing 1.27  $\mu\text{m}$  dayglow is used as a tracer for ozone above ~ 20 km. The rotational temperatures retrieved from O<sub>2</sub>(a-X) emissions showed a mean of  $172 \pm 2.5$  K, confirming that the sensed ozone lies in the middle atmosphere (~24 km). Retrieved vertical column densities for ozone ranged between 1.5 and 2.8  $\mu\text{m-atm}$  at mid- to low-latitudes (30° S - 60° N) and decreased outside that region. A significant decrease in ozone column density was seen near 30° N (close to the sub-solar latitude of 23.5° N). The  $\nu_1$  fundamental band of HDO near 3.67  $\mu\text{m}$  was used as a proxy for H<sub>2</sub>O. The retrieved vertical column abundance of water varied from 3 pr- $\mu\text{m}$  at ~ 30° S to 24 pr- $\mu\text{m}$  at ~ 60° N. These results were in good agreement with current photochemical models and with measurements obtained by spacecraft and other methods, establishing this as a new approach for investigating photochemistry on Mars.

*Mars Atmosphere and Dust in the Optical and Radio (MATADOR).* W. Farrell, J. Houser, and M. Desch were involved in a third desert campaign under the auspices of the MATADOR program, this to quantify the fluid and electrical properties of dust devils. Triboelectricity creates copious dust grain charging which is measurable in electric and magnetic detecting systems as a devil passes an observation point. This year, LEP scientists provided magnetic search coil antennae to the investigation and are continuing their work on the dust devil as a solenoid radiator of ULF magnetic emission.

## 5.4 Jupiter

*Atmospheric Composition.* G. Bjoraker and T. Hewagama are using spectra of Jupiter acquired with the CSHELL spectrometer at NASA's IRTF in Hawaii to study the planet's deep atmosphere. Observations of absorption lines of CH<sub>4</sub> and NH<sub>3</sub> were obtained nearly simultaneously with measurements by the CIRS on the Cassini spacecraft during the Jupiter flyby in December 2000. Additional observations were performed at the same time as the Near Infrared Mapping Spectrometer (NIMS) instrument on Galileo was observing Jupiter in August 1999. The methane and ammonia observations are sensitive to the presence of water clouds between 3 and 7 bars on Jupiter. This technique permits the separation of the deep water cloud from overlying cloud layers. Detailed modeling reveals interesting variations in the opacity of the water cloud within the Great Red Spot and between belts and zones on Jupiter.

P. Romani collaborated with D. Jennings, G. Bjoraker, P. Sada (Universidad de Monterrey) and G. McCabe on analysis and interpretation of observations of Ethylene on Jupiter. Ethylene was detected in high air mass observations in the equatorial region and in the polar regions. The ethylene emission from the poles was enhanced in the regions where aurora are seen in X-ray, UV, and near infrared images (i.e. the auroral "hot spot"). In 2000 they measured a short-term change; the emission in the hot spot decreased by a factor of three over a two-day interval. This transient behavior and the sensitivity of ethylene to temperature changes near its contribution peak at 5-10 microbar suggests that the polar enhancement is primarily a thermal effect.

*Continuing Studies of Jovian Mid-IR Aurora.* The study of long and short term variability of mid-IR auroral emission from Jupiter's poles continues. The data T. Kostiuk with Co-investigators T. Livengood, F. Schmölling, D. Buhl, K. Fast, T. Hewagama, and J. Goldstein obtained with HIPWAC in December 2000 and in February 2001, during the Cassini spacecraft flyby of Jupiter has been analyzed and added to the long term data base. Results complemented spacecraft measurements by the Cassini CIRS and show more modest increase in the measured ethane emission compared to previous ground-based and Voyager IRIS results near periods of solar maximum. Both ethane abundances and thermal structure were obtained globally as well as for the auroral regions.

*Temporal Study of Shoemaker-Levy 9 (SL-9)-Introduced Ammonia in Jupiter's Stratosphere.* K. Fast, with co-investigators T. Hewagama, T. Kostiuk, P. Romani, F. Espenak, A.L. Betz, R.T. Boreiko (University of Colorado, Boulder) and T. Livengood, studied the temporal behavior of introduced ammonia and temperatures in the stratosphere of Jupiter following the impact of Comet SL-9 fragments G and K, measured with Infrared Heterodyne Spectroscopy (IRHS). Spectra were acquired from hours to 18 days following the impacts, enabling an investigation of the temporal behavior of ammonia abundance and temperatures in Jupiter's stratosphere. Results are consistent with the work of J. Harrington (Cornell University) and D. Deming for upper atmospheric heating and introduction of material by "splashback" of the material ballistically ejected from Jupiter's atmosphere by the impact. The integrated mass of ammonia suggests that the observed ammonia was excavated from Jupiter's deep atmosphere rather than introduced by the comet fragments' dissolution. Ammonia concentrations after impact decrease significantly faster than expectation from photolytic destruction. The last set of observations, however, suggests additional lower-altitude sources of ammonia supporting the concentration in the lower stratosphere.

*Planetary Radio Bursts.* C. Barrow, R. MacDowall, and others analyzed extensively the polarization and beaming of Jovian broad-band kilometric (bKOM) and hectometric (HOM) radio emission. Using Ulysses observations when the spacecraft was at 5 AU from Jupiter, they found that HOM bursts were observed at latitudes consistent with a cyclotron maser emission mechanism, whereas the bKOM observations were not consistent with cyclotron maser.

R. Hess and R. MacDowall studied interplanetary scattering at low frequencies ( $\sim 100$  kHz) using Jovian radio emissions as the sources. The magnitude of the scattering was found to vary with wavelength as expected from analytic theory; however, there is considerable scatter from event to event, due to variations in the intervening density and density fluctuations.

## 5.5 Saturn

A. Simon-Miller, J. Hillman, N. Chanover (New Mexico State University) and graduate student Takafumi Temma (New Mexico State University) were involved in a ground-based observing program of Jupiter and Saturn. This program included time on the Air Force Research Laboratory's 3.67-meter AEOS telescope, operated at the Maui Space Surveillance System, in February 2002. The GSFC Acousto-optic Imaging Spectrometer (Principal Investigator, D. Glenar), was used as a guest instrument to acquire hyperspectral image cubes for atmospheric modeling and spectral analysis.

*Modeling Pickup Ions at Icy Satellites.* E. Sittler, as Cassini Plasma Spectrometer (CAPS) Co-investigator, is studying pickup ions at Dione and Enceladus. His model includes a sputtered atmosphere for each icy satellite and ion production produced by photoionization, charge ex-

change and electron impact ionization. The atmosphere is assumed to be optically thin and finite gyro-radii effects are shown to be small. The sputtered atmosphere is dominated by water molecules with assumed 10% abundance of  $H_2$ ,  $O_2$ ,  $NH_3$  and  $CO_2$ . As a fluid element passes through the atmosphere, ions are accumulated by the ionization mechanisms noted above to yield a pickup ion density at the assumed observation point where the Cassini spacecraft is located. This information is then used to observe simulated data products that would be produced during the icy satellite encounters. These data products are in the form of ion distribution functions and energy-TOF spectrograms. The ambient ions are assumed to be convected Maxwellians, while the pickup ions are assumed to be in ring distributions. The simulations show that one can easily distinguish the two. They also show that one can see ammonia for wake passes, but not upstream passes. Wake passes are a factor of ten more sensitive than upstream passes. The observed ion abundances of pickup ions can be used to determine the composition of the icy satellite surfaces.

## 5.6 Titan

*Near-IR Spectral Imaging of Titan.* Spectral imaging of Titan has been conducted on two successive years, using a GSFC-built acousto-optic camera at the Mt. Wilson 100 inch natural guide star adaptive optics facility. N. Chanover is the Principal Investigator and D. Glenar is the Co-investigator. Other team members include J. Hillman, W. Blass (University of Tennessee), C. McKay (NASA Ames) and P. Rannou (University of Paris). The objectives have been to observe Titan in and out of the 0.94 micron methane "window" and at selective wavelengths that are sensitive to absorption and scattering, in order to investigate the temporal nature of Titan's lower atmosphere. The first-year data has been processed and is being modeled using two complementary radiative transfer codes that treat Titan's haze particles as spheres and as fractals, respectively. The models are being used to match the observed limb darkening curves across Titan, and information about the presence of rain as a clearing mechanism for the lower troposphere is being inferred.

*Titan Atmospheric Composition.* T. Livengood, T. Hewagama, T. Kostiuk, K. Fast, and J. Goldstein made an improved determination of ethane abundance and established constraints on the global thermal structure on Titan. The improved value for the concentration of ethane in Titan's stratosphere is somewhat lower with error bars reduced by a factor of several relative to the prior literature.

## 5.7 Extra Solar Planets

*Study of Extra-Solar Planetary Systems.* T. Hewagama with Co-investigators R. Barclay, T. Chen, D. Deming, C. Goukenleuque, M. Greenhouse, R. Henry, M. Jacobson, B. Mott, S. Satyapal, and D. Schwinger reported on their work on "Spectral Contrast Enhancement Techniques for Extrasolar Planet Imaging" at the

Scientific Frontiers of Research in Extra-Solar Planets Meeting held in Washington D.C., in June 2002. Extrasolar planet imaging techniques for future missions which involve shaped and apodized pupil coronagraphy were discussed. These techniques may be enhanced by exploiting the extrasolar planets spectral signature, which shows contrast between particular spectral regions. Frequency switching techniques, based on such spectral contrast, as potential methods for improving the imaging capability of pupil plane optimized systems are also being studied.

*VLA Investigation of the Extrasolar Planet About Tau Boo.* LEP Investigators (W. Farrell, M. Desch) obtained radio telescope time on the Very Large Array to examine the radio field about Tau Boo for radio evidence of its extrasolar planet. The observations were carried out by the 27-antennae array (each antenna a 25-m diameter dish) in May 02. Previous theoretical study suggests that the extrasolar planet about Tau Boo should radiate electron cyclotron emission at levels about 1000-10000 times that of Jupiter at frequencies below 100 MHz, making it a prime candidate for study. Data analysis of this recent observation interval is ongoing.

## 5.8 Asteroids and Comets

*Near-Earth Asteroid Rendezvous (NEAR).* The NEAR-Shoemaker remote-sensing X-ray/Gamma-ray Spectrometer (XGRS) completed more than a year of operation in orbit and on the surface of 433 Eros. Elemental compositions for a number of regions on the surface of Eros have been derived from analyses of the characteristic x-ray and gamma-ray emission spectra. The NEAR XGRS detection system was included as part of the Interplanetary Network (IPN) for the detection and localization of Gamma-ray Bursts (GRBs). Preliminary results for both the elemental composition of the surface of Eros and the detection of GRBs have been obtained. In addition to the science results, a number of factors relative to the design and operation of future planetary remote and in-situ XGRS instruments were determined from an analysis of the operation of the NEAR XGRS system. The results were published in a special NEAR issue of "Meteoritics & Planetary Science," Vol. 36, No. 12, December 2001.

*Sodium at Comets.* K. Ogilvie and M. Coplan (University of Maryland) are preparing a paper based upon new measurements of desorption of sodium from silicate grains. In addition to explaining the presence of sodium in the atmospheres of Moon and Mercury, this process may apply at comets. Using recently measured cross sections for this process they intend to show agreement between the measured fluxes of sodium in comet tails and comas, and estimates of sodium optical observations, incidentally confirming the International Cometary Explorer (ICE) ion measurements at  $M/Q=24$ .

*The Organic Composition of Comets.* M.J. Mumma reviewed the group's cometary research program at several major international conferences. To date, organic volatiles and water in eight Oort cloud comets were in-

vestigated at infrared wavelengths. The detected parent species include  $H_2O$ ,  $CO$ ,  $CH_3OH$ ,  $CH_4$ ,  $C_2H_2$ ,  $C_2H_6$ ,  $OCS$ ,  $HCN$ ,  $NH_3$ , and  $H_2CO$ . Several daughter fragments ( $CN$ ,  $OH$ ,  $NH_2$ , etc.) are also measured;  $OH$  prompt emission provides a useful proxy for water when  $H_2O$  itself is not measured. Long-slit spectra are taken at high spectral dispersion and high spatial resolution, eliminating many sources of systematic error. The resulting parent volatile production rates are highly robust, permitting a sensitive search for compositional diversity among comets. For six comets, data reduction is complete. Five exhibit similar compositions (excepting  $CO$ ), and also agree with comet Halley. Their low formation temperatures ( $\sim 30K$ ) suggest this group probably formed beyond 30 AU from the young sun. However, a sixth OC comet, C/1999 S4 is severely depleted in hypervolatiles and also in methanol, and it likely formed near 5 - 10 AU. This represents the first clear evidence for compositional diversity among comets that formed in the giant-planets' region of the protoplanetary disk.

*Comet C/2002 C1 Ikeya-Zhang.* M. Mumma, N. Dello Russo, M. DiSanti, K. Magee-Sauer and E. Gibb investigated the composition of C/2002 C1 Ikeya-Zhang at infrared wavelengths. This Oort-cloud comet was discovered in February 2002, and Target-of-Opportunity time was awarded at the NASA IRTF in March and April. The comet was unusually bright, rivaling comet Hyakutake during its close approach to Earth. The long-slit spectra featured both high spectral dispersion and high spatial resolution about the nucleus, permitting the extraction of rotational temperatures, production rates, and spatial information along the slit. The chemistry of comet Ikeya-Zhang was consistent with that of five other Oort cloud comets (excepting  $CO$ ).

*Search for HDO in Comets.* E. Gibb, M. Mumma, M. DiSanti, N. Dello Russo, and K. Magee-Sauer searched for HDO emission in our infrared database of six Oort Cloud comets (C/2002 C1 (Ikeya-Zhang), C/2001 A2 (LINEAR), C/2000WM1 (LINEAR), C/1999 H1 (Lee), C/1999 S4 (LINEAR), and C/1999 T1 (McNaught-Hartley)). Spectral lines of the  $\nu_1$  fundamental vibrational band of HDO were sampled using high-resolution infrared spectra acquired with both CSHELL at NASA's IRTF and NIRSPEC at the W.M. Keck Observatory. Of these comets, the recent apparition of the bright comet Ikeya-Zhang, with its high gas production rate and good geocentric Doppler shift, provided an exceptional opportunity to search for minor constituents such as HDO. HDO was tentatively detected in three comets and upper limits were determined for the remaining three. These data, combined with future observations, will be used to test models of nebular chemistry and delivery of water and organics to the early Earth.

*Comet C/1996 B2 Hyakutake.* M. Mumma, M. DiSanti, N. Dello Russo, K. Magee-Sauer re-analyzed their observations of Comet C/1996 B2 Hyakutake, using algorithms and procedures developed during their Hale-Bopp campaign. The initial reductions were based on nucleus-centered extracts only, and they neglected opti-

cal depth effects. The revised analyses are based on spatial profiles about the nucleus, and they include corrections for optical depth along with various other improvements and minor corrections. The long-slit infrared spectra featured both high spectral dispersion and high spatial resolution about the nucleus, permitting the extraction of rotational temperatures, production rates, and spatial distributions of species along the slit. The spatial distributions of  $C_2H_6$ , HCN, and  $H_2O$  in the coma are consistent with their release directly from the nucleus, although asymmetries about the nucleus are seen for both gas and dust. CO shows a small distributed source. The measured spatial distribution for HCN was consistent with its release at the nucleus - no significant contribution from a distributed source is required within  $\sim 600$  km of the nucleus.

*Comet C/1995 O1 Hale-Bopp.* M. DiSanti, M. Mumma, N. Dello Russo, and K. Magee-Sauer published their study of carbon monoxide production in Hale-Bopp during its recent apparition. They first detected CO at 4.1 AU pre-perihelion in June 1996, and followed its heliocentric evolution through perihelion at 0.9 AU until September 1997 (2.8 AU). The spatial distribution of CO molecules in the coma revealed two distinct sources for CO, one being CO ice native to the nucleus, and another being CO released from a progenitor distributed in the coma. Only the native source was seen when the comet was beyond 2 AU from the Sun. The measured high ethane abundance relative to acetylene in Hale-Bopp suggests its ices were altered by radiation processing and/or hydrogen-atom addition reactions on the surfaces of ice-mantled grains in the natal cloud. These results are not consistent with ices in Hale-Bopp originating in a thermally or chemically equilibrated region of the solar nebula.

## 6 SUN-EARTH CONNECTIONS

### 6.1 Ionospheric, Thermospheric, and Mesospheric Physics

*SAMBA Ground Magnetometers.* D. Sibeck is a Co-investigator in the South American Meridional B-field Array (SAMBA), an ambitious NSF-funded program to study the ionospheric response to varying solar wind conditions, determine plasmaspheric densities, and conjugate signatures by placing UCLA magnetometers throughout the length of mainland Chile and its Antarctic territories. During March 2002, he installed the first magnetometers in Patagonia and the Lake Region of Southern Chile. The remainder of the array will be installed during the course of 2002-2003. E. Zesta (UCLA) is the Principal Investigator for the project.

*Traveling Convection Vortices (TCVs).* TCVs, transient swirls of equivalent ionospheric convection observed in high-latitude dayside ground magnetograms, represent a fundamental mode of solar wind-magnetosphere interaction. Working together with colleagues at INPE in Brazil and UCLA in California, D. Sibeck has demonstrated that weak, but repeatable signatures can be iden-

tified in global ground magnetograms at the times of TCVs. The global signatures appear to originate near dawn or dusk in response to orthospiral or spiral IMF orientations and reach greatest strength near local noon under the equatorial electrojet. The TCVs themselves generally reach peak amplitudes on magnetic field lines that map to the inner edge of the low-latitude boundary layer and in the dawn (dusk) side ionosphere during periods of spiral (orthospiral) IMF orientation, in accordance with MHD model predictions.

#### *Plasma Irregularities in Equatorial Ionosphere.*

Plasma irregularities in the nightside F region are investigated using data from the ROCSAT-1 and DMSP satellites. The data reveal the presence of localized, discrete density enhancements in addition to the well known equatorial spread F (ESF) plasma depletion structures in the nightside F region. Simultaneous observations from ROCSAT-1 at  $\sim 600$  km and DMSP at  $\sim 800$  km indicate that the density enhancement structures occur in association with equatorial spread F (ESF) plasma depletions. They generally occur near the poleward edges of the plasma depletions in the equatorial anomaly region,  $\sim 10^\circ$  to  $20^\circ$  from the magnetic equator. They have sharp, distinct edges and appear to have similar scale sizes and density fluctuation spectra as in plasma depletions. The results suggest that the density enhancement structures are caused by the polarization electric field which is generated within the equatorial plasma depletions and maps to the anomaly latitudes along the magnetic field lines. The research was conducted by G. Le and R.F. Pfaff, in collaboration with C.-S. Huang of MIT Haystack Observatory, S.-Y. Su and H.C. Heh of National Central University, Taiwan, R.A. Heelis and M. Hairston of University of Texas at Dallas, and F.J. Rich of Air Force Research Laboratory.

*Solar Proton Events and the Fair Weather Electric Field at Ground.* W. Farrell and M. Desch created an analytical model of the expected changes in the fair-weather electric field driven by all global thunderstorms during intense solar proton events. In essence, an attempt was made to model the effects on the most electrically active systems at low altitude (thunderstorms) with the disturbed solar conditions. The model predicts that the fair-weather field at ground can be disturbed by 10's of %, but such electric effects are small compared to those from the passage of local thunderstorms.

### 6.2 Magnetospheric Physics

*Excitation of Lower Hybrid Waves in the Plasma Sheet Region.* D. Fairfield, A. Sundaram and A. Figueroa-Viñas are combining theory and observations by Geotail and other International Solar Terrestrial Physics (ISTP) missions to understand dissipation in the magnetotail plasma sheet. The excitation of lower hybrid waves in the plasma sheet using fluid and kinetic equations is investigated both in the electrostatic and electromagnetic limits. Considering the tail magnetic field configuration, the linear stability theory of lower hybrid waves is studied by including the effect of a magnetic field gradient in

the South-North direction. In the fluid case, the dispersion characteristics are examined for wavelengths (along dawn-dusk direction) less than or greater than plasma skin depth. In the kinetic limit, the effect of wave particle resonance such as the curvature drift and gradient-B resonances is included and the analytical estimate shows that both electrostatic and electromagnetic waves are excited for certain ranges in the wavelength spectrum. The preliminary work initiated here highlights the possibility that lower hybrid waves can indeed play a role in producing the anomalous dissipation for the magnetic reconnection and substorm onset. Extensive numerical work, both in fluid and kinetic limits, is in progress.

*Forecasting the Radiation Belt Environment.* A radiation belt-ring current forecasting model, called the Radiation Belt Environment (RBE) model, has been developed by M.-C. Fok and Y. Zheng. This is one of the ongoing projects of the University Partnering for Operational Support (UPOS) program, which is sponsored by the US Air Force, involving collaboration between NASA (GSFC and Marshall Space Flight Center (MSFC)), Universities (UAK and JHU) and other government agencies (AFRL). The goal of this project is to develop a model that can predict the radiation belt environment and the corresponding radiation doses, 24 hours ahead of time. Special features of this model include: plasma distributions with a local-time dependence, self-consistent calculation of particle decay due to wave-particle interactions, and a model driven solely by solar wind conditions. The current version of the RBE model has been delivered to JHU APL for routine operation. At APL, near real time solar wind Advanced Composition Explorer (ACE) data from NOAA are input to the model, which outputs energetic electron and ion fluxes in the inner magnetosphere every 15 min.

*ISIS Digital Database.* Digital ISIS 1 topside-sounder ionograms continue to be produced, from the original analog telemetry tapes, by a team led by R.F. Benson. They are being archived at the NSSDC at GSFC to augment some 300,000 digital ISIS-2 ionograms covering the 12-year interval from the end of 1971 through early 1984. The analog-to-digital conversion of selected Alouette-2 telemetry tapes is planned. Programs to assist in the retrieval of the data, to produce electron-density profiles from the echo traces, and to help interpret sounder-stimulated ionospheric plasma resonances are available from <http://nssdc.gsfc.nasa.gov/space/isis/isis-status.html>.

*Intense UH Bursts Near a Tail Reconnection X-line Region.* Wind investigators, W. Farrell, M. Kaiser, and M. Desch discovered very intense upper hybrid plasma wave bursts in the near vicinity of a tail reconnection X-line at -57 Re during a Wind tail passage. The emissions had amplitudes near 40 mV/m, and were strongly polarized with a wave normal vector oriented at oblique angles to the ambient magnetic field. The bursts tended to be observed near the edges of the separatrix defining inflowing and outflowing plasma. While recent Wind studies have determined that collisionless processes are

involved in ion cross-field migration, the processes associated with electron cross-field transport have not been identified. The observation of such large-amplitude UH electron plasma waves may indicate the nature of the kinetic processes involved in electron acceleration in the X-line region.

*Observational Evidence for Self-organized Criticality in the Magnetotail Plasma Sheet.* A. Klimas, D. Vasiliadis, V. Uritsky, and R. Weigel suspect that Earth's magnetotail plasma sheet is in or near self-organized criticality. If so, then spatiotemporally localized reconnection events in the plasma sheet may play the role of dissipation (avalanche) events in mathematical models of self-organized criticality. Observations have shown that these localized reconnection events are strongly correlated with disturbances in the ionosphere. They have investigated some statistical properties of the ionospheric disturbances with the expectation that these disturbances may reflect the dynamics of the plasma sheet. The correlation between localized auroral brightening and localized plasma sheet reconnection has been shown to be particularly strong. They have examined the statistical properties of auroral brightening observed by the UVI experiment onboard the Polar spacecraft with the expectation that these statistics may also reflect the dynamics of the plasma sheet. The Klimas group found a variety of scale-free power-law distributions over as much as five decades of scale-size, limited only on the low end of the distributions by experimental resolution and on the high end by the spatial dimensions of the auroral region. These remarkable distributions constitute strong evidence that localized reconnection in the plasma sheet leads to a self-organized critical avalanching system that is scale-free over a broad range of scales. If the distributions imply Self-Organized Criticality (SOC) in the plasma sheet, then the bright regions should exhibit other known properties of avalanching systems in SOC. The Klimas group has demonstrated that, on average, the bright region evolution is consistent with the behavior known as "spreading," in the general context of critical phenomena in many-body systems. They have shown that the so-called dynamical critical exponents controlling the spreading dynamics are consistent with the statistical exponents governing the scale-free UVI distributions.

*Plasma Physical Models of Self-organized Criticality in the Magnetotail Plasma Sheet.* Traditionally, self-organized criticality is studied using so-called "sandpile" mathematical/numerical models. While useful for some purposes, the utility of these models for understanding the dynamics of the plasma sheet is limited. The Klimas group has embarked on a study of plasma physical models of self-organized criticality that are generally composed of a magnetohydrodynamic (MHD) basis, modified by an idealized representation of kinetic phenomena that are activated when and where the MHD approximation fails. The widely divergent natural scales of these two components, when they are strongly coupled, allows for multi-scale behavior in the intervening range and for

the possibility of scale-free self-organized criticality. The Klimas group has demonstrated self-organized criticality in a one-dimensional version of these models. A two-dimensional model is presently under study. Very long numerical runs that are necessary to allow the model to evolve into a self-organized configuration have been achieved. A mechanism for explaining the scale-free UVI distributions has been demonstrated and it has been shown that this mechanism is responsible for the generation of intermittent turbulence in the MHD plasma.

*L-shell Structure of the Outer Zone in the Electron Radiation Belts.* Earlier research has shown that the response of relativistic electrons to solar wind speed variations depends significantly on the L shell, among other parameters. Correlations of the flux time series at different L shell regions further support the notion that the outer zone is divided in three regions. The nearest one to Earth,  $P_0$ , at approximately  $L=3-4$ , responds within hours and its response lasts 2-3 days. Region  $P_1$ , at approximately  $L=4-7$ , is the heart of the outer zone, responds within 2 days and the response lasts for 5 days or longer. Further out, region  $P_2$ , at  $L>7$ , is strongly influenced by the cusp and plasma sheet activity, and its response lasts several hours. The sizes of  $P_1$  and  $P_2$  vary considerably with solar cycle activity with  $P_2$  growing with the solar cycle in detriment of  $P_1$ . Their boundary effectively set by the long-term dynamics of the magnetopause. The size of  $P_0$  remains unchanged with the solar cycle. The Klimas group has put these results together from separate analyses of Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX)/PET, GPS-33/BDD-II, and, for comparison purposes, EXOS-C/HEP, spanning a period of more than 12 years. The characteristics of the three regions suggest different families of injection and diffusion processes in the inner magnetosphere.

*Predictability of Spatiotemporal Fluctuations in Ground-level Magnetic Disturbances.* A neural network model that directly predicts the level of temporal fluctuations in ground-level magnetic disturbances in a fifteen-minute time interval has been developed by the Klimas group. The model is driven by solar wind data from the ACE satellite and has been tested on 30 auroral zone magnetometer stations for nearly all days of 1998. These filters show that the local times that have a large average amplitude of temporal magnetic fluctuations often have a high predictability. The model has now been modified to predict the amplitude of the ground magnetic field. From this, the relative influence of different driving processes, such as reconnection and Kelvin-Helmholtz instability, has been estimated using the relative influence of the solar-wind variables on the model.

*Magnetosphere Magnetic Field Modeling.* N. Tsyganenko continued data-based modeling of the Earth magnetosphere. Most of the recent work concentrated on modeling major storms in the near and inner magnetosphere. Strong geomagnetic storms are relatively rare events, represented by only a small fraction of the data used in deriving previous empirical models. Using

those models to represent the storm-time magnetosphere is at best an extrapolation, based on trends derived from quiet and moderately disturbed data. To overcome that limitation, a set of spacecraft magnetometer data containing only clear-cut storm events with  $Dst < -70$  nT was created. The final data set included 37 storms between 1996 and 2000 and comprised magnetometer data taken in the inner and near magnetosphere by Polar, GOES-8, -9, -10, Geotail, and Equator-S. All the magnetospheric data were accompanied by concurrent Wind or ACE observations of the solar wind and interplanetary magnetic field. Modeling of the strongly disturbed magnetosphere revealed an enormous distortion and large dawn-dusk asymmetry of the inner magnetosphere caused by the combined effects of the symmetric and partial ring, cross-tail, and Birkeland currents. During major storms with  $Dst < -250$  nT, the nightside magnetic field can become tail-like only 3.5-4.0 RE from Earth. This may explain observations of auroral expansion to very low latitudes during extremely strong storms. It may also explain impulsive injections of energetic particles deep into the inner radiation belts. Finally, it imposes serious constraints on dipole approximations for the inner magnetospheric magnetic field during storm simulations.

*Magnetospheric Plasma Models.* N. Tsyganenko developed the first data-based model for ion densities, temperatures, and pressures in the Central Plasma Sheet (CPS) as functions of position in the magnetotail and the solar wind and IMF conditions. The model is based on in-situ Geotail LEP measurements from 1994 to 1998 at distances from 10 to 50 Re downstream in conjunction with Wind and IMP-8 solar wind and IMF observations. The ion density, which exhibits the greatest variability, is controlled primarily by the solar wind proton density and the northward IMF component. Model and observed temperatures correlate better, and the temperature is controlled primarily by the solar wind speed and the IMF orientation. Model and observed CPS ion pressures are well correlated ( $R=0.96$ ). Confinement by the external tail lobe magnetic field results in an approximately force-balanced CPS. Consistent with the observed dawn/dusk symmetry of the tail lobe magnetic field, the CPS beyond 10 Re is also very nearly symmetric. CPS and solar wind ion densities are positively correlated, as are CPS densities and IMF  $B_z$ . CPS temperatures and solar wind velocities are positively correlated, whereas CPS temperatures and IMF  $B_z$  are negatively correlated. The plasma ion density decreases from the tail flanks towards midnight, whereas temperatures peak near midnight and diminish towards the flanks. The CPS ion pressure is nearly constant across the mid-tail (20-50 Re); at closer distances the isobars gradually bend and approximately follow contours of constant geomagnetic field projected into the equatorial plane. For northward IMF conditions combined with a slow solar wind, this transition occurs at much larger distances, reflecting a weaker tail current and hence a more dipole-like magnetic field.

*Modeling of Collisionless Magnetic Reconnection.* M. Hesse and M. Kuznetsova have performed kinetic

simulations of component reconnection. Reconnection proceeds in a current sheet with a  $104^\circ$  magnetic field rotation. As a result, magnetic reconnection forms distinctively different signatures from what was found from kinetic models of anti-parallel reconnection. In particular, ion and electron flow patterns are substantially distorted, the shear magnetic field component does not exhibit a quadrupolar structure, and electron orbits in the diffusion region are substantially modified. The emphasis of the investigation was on the modifications to the diffusion region, with particular emphasis on the electron diffusion zone. They found that electron pressure nongyrotropies can support collisionless magnetic reconnection even when the electron motion in diffusion region is strongly affected by the guide magnetic field.

*Modeling of the Magnetospheric Response to Solar Wind Variations.* As part of a science-based validation study, K. Keller, L. Rastätter, M. Hesse, and M. Kuznetsova performed global MHD simulations of the magnetospheric response to solar wind variations. In the first of two studies, they simulated the impact of a solar wind kinetic pressure step increase on the magnetosphere-ionosphere system. The pressure variation generated field-aligned currents, and modified ionospheric convection patterns. Rather than quasi-static, this process was found to be time-dependent, with Alfvén-wing type structures trailing the impacting pressure variation. In a second study, they analyzed the topological changes of the geomagnetic field if the IMF exhibits strong east-west components. It was found that reconnection processes at the magnetopause are able to change the magnetic connectivity between northern and southern hemisphere drastically, leading to very large longitudinal separations between magnetically conjugate foot points.

*Plasma Transport and Energization.* T. Moore, M.-C. Fok, B. Giles, and W. Allen have continued to explore the transport and energization of plasmas in the Earth’s magnetosphere, using theoretical tools guided by observations. Studies range from the entry of solar wind and ionospheric plasmas into the magnetospheric cusp regions, including the distribution of dayside reconnection, to the transport through the polar caps and lobes into the plasma sheet, to the formation of the ring current and the relativistic radiation belt electrons.

*Ionospheric Electrodynamics During Substorms.* J. Gjerloev and R. Hoffman have used global auroral images to investigate the behavior of the auroral electrojet indices AU and AL during substorms. A superposition of the 12 AE stations onto global auroral images and identification of the stations contributing to AU and AL enabled an understanding of the temporal as well as spatial behavior of the indices with respect to substorm onset location and timeframe. Based on this simple technique, it was found that at substorm onset the AL contributing station makes a characteristic jump from a location near the dawn terminator to the substorm onset region and then jumps back to the dawn hours in the early recovery phase. The observations indicate a local minimum

in the westward electrojet intensity near midnight. The defining AU station does not show any similar systematic behavior. The observations can be explained by the two-component westward electrojet concept and understood in the context of the self-consistent substorm model by Gjerloev and Hoffman. The characteristic decrease in AL is due to the introduction of the substorm current wedge which leads to the westward jump in the location of the AL defining station from the post-midnight convection electrojet to the pre-midnight wedge electrojet. During this time the AL defining station is typically located near the poleward edge of the surge region where the model indicates the wedge electrojet position.

### 6.3 Heliospheric and Solar Physics

*Foreshock Cavities.* Processes within the foreshock significantly modify the solar wind shortly prior to its interaction with the bow shock and magnetosphere. Working together with colleagues from the University of California, Berkeley (UCB) in California, D. Sibeck demonstrated that the plasma and magnetic field properties of two foreshock cavities observed by Wind confirm those predicted by kinetic code simulations. Statistical studies surveying the dependence of cavity properties with radial distance from Earth using Wind observations are now underway with colleagues at UCB, whereas statistical studies surveying their dependence on local time and solar wind conditions are now underway with colleagues at Imperial College, Queen Mary Westfield, and CNES in the United Kingdom and France.

*Electrons at Shocks.* J. Fitzenreiter, K. Ogilvie, and S. Bale (UCB) have examined exceptionally well observed interplanetary fast forward shocks of varying strength from the Solar Wind Experiment (SWE-VEIS) data set from the Wind spacecraft for heating and particle acceleration. All are perpendicular or quasi-perpendicular. Downstream velocity distribution functions have been compared with those predicted by mapping upstream distribution functions through the discontinuities using Louiville’s theorem and the de Hoffman-Teller electrostatic potential. Good agreement is found, and electron beams are observed at the stronger shocks. The de-Hoffman-Teller potentials range between 30 and 100 volts.

*Co-rotating Interaction Regions (CIRS).* K. Ogilvie and E. Roelof (JHU/APL) continue to study Ulysses-SWICs particle observations. The objective is to explain quantitatively ion observations near reverse shocks, and elucidate the previously discovered relationship between ion flux and plasma temperature.

*Interplanetary Shock Geometry in the Magnetosheath.* A. Szabo, in collaboration with C.W. Smith (Bartol Research Institute, University of Delaware) and R. Skoug (LANL) continued their multi-spacecraft analysis of the interplanetary shock surface curvature. The study focussed on the geometry of interplanetary shocks in the Earth’s magnetosheath. The transmitted pressure surfaces maintain the same geometry as the impinging shocks. This result is significant for accurate space

weather forecasting of interplanetary shock induced geomagnetic activities.

*Earth's Bow Shock.* A. Szabo, in collaboration with J. King (GSFC), J. D. Richardson (MIT) and J. Merka have been analyzing all of the Earth bow shock crossings observed by the IMP 8 spacecraft. Fifteen years of observations have been analyzed and the complete database is being placed in a publicly searchable database at the National Space Science Data Center (NSSDC). Crossing locations often differ greatly from those predicted, indicating a need to improve upon current bow shock models.

*Invited Review Paper.* R. Lepping was invited recently to present a review chapter on the solar wind's role in Space Weather in a book by Research Signpost, Trivandrum, India, in a series called Recent Research Developments in Geophysical Research. The chapter is tentatively entitled, "Sun-Earth Electrodynamics: The Solar Wind Connection." It provides some background to the subject and concentrates on the recent work by a team in LEP studying transient interplanetary structures, magnetic clouds, and their solar and geomagnetic connections, and balances this with discussion of the importance of quasi-periodic solar wind structures. According to plan, the book is to be published in late 2002. D. Berdichevsky and C.-C. Wu are contributing to the review.

*Estimating Errors on Magnetic Cloud Fit Parameters.* R. Lepping, joined by D. Berdichevsky and T. Ferguson as coauthors, gave a talk at the Spring 2002 AGU Meeting entitled "Can Estimating Errors in Force Free Magnetic Cloud Model Fit-Parameters Be Fun?" The study employed a Monte Carlo technique to simulated magnetic clouds whose composition was exactly specified and added "noise." The noise, in order to have realistic structural characteristics, was developed from actual magnetic clouds from Wind observations. Specifically, the noise comprised difference fields, i.e., those fields resulting from subtracting modeled fields from the actual observed fields. The results provided information on the limitations of the cloud-fitting program. For example, it is common for error cone angles and percent error on field intensity to be around 25° and 7 - 10%, respectively. Closest approach errors are usually the largest, typically around 30%. The study further gives a practical scheme for using the results to help estimate errors on the various fit-parameters in future studies.

*Magnetic Cloud Triggering Locations of Single and Multi-phase Magnetic Storms.* Wind observations have been used to study the geomagnetic effects of 34 interplanetary magnetic cloud "complexes." Particular efforts have been devoted to determining the causes of multi-phase storms, in which multiple minima occur within in a few days. Cloud complexes include the magnetic clouds themselves, upstream shocks when they occur, the intervening magnetosheaths, and the specific interplanetary regions associated with the each phase of dual phase storms. The leading and trailing parts of the clouds were examined separately. Two other related

studies are underway. One study uses many decades of IMP-8 data to determine how magnetic cloud complexes trigger magnetic storms. The second study, supported by a new two-year Living with a Star grant, will determine whether it is possible to predict the latter half of a magnetic cloud's BZ field from the earlier half; BZ plays a key role in driving geomagnetic storms. In contrast to previous studies that used accumulated event profiles, the present study employs a force-free cloud magnetic field structure to improve Dst (geomagnetic index) predictions.

*2-D Curvature of Large Angle MHD Discontinuity Surfaces.* R. Lepping and C.-C. Wu used IMP 8 and Wind observations from 1995 to 1999 to identify 134 thick  $\sim 14 R_e$  solar wind "directional discontinuities" (DDs) across which the field orientation rotated by some 90 to 180°, usually representing thick structures. Tangential and rotational discontinuities were distinguished and the degree of surface curvature (on average 140°) was determined. A typical radius of curvature is 380  $R_e$ . Since the average radius of curvature of an interplanetary shock surface has been estimated to be about 1AU at 1AU, the curvature of DD surfaces is typically 60 times larger than that of shock surfaces. Many DDs changed type from one position to the other. This work took place over a period of a few years with the help of a high school student, a high school teacher, and a post-doctoral fellow.

*Geometrical Model of the Expansion of Magnetic Flux Ropes.* Together with C. Farrugia (University of New Hampshire), D. Berdichevsky and R. Lepping have developed a means of representing the 3-D expansion of magnetic flux ropes that is applicable to interplanetary clouds and possibly to some [small] magnetotail flux ropes. The formulation is completely consistent with Maxwell's equations and, in particular, with temporal conservation of flux as the rope passes the observing spacecraft. Earlier attempts considered only 2-D expansion, i.e., that part that was characterized by velocity components perpendicular to the cloud's axis. This represents the beginning of a modified magnetic cloud fitting program that will be able to accommodate the large fraction of clouds that are expanding, with the goal of better representing the magnitude-profile of a cloud's field.

*Evidence for a Secondary Stream of Interstellar ENA 30° from the Upstream Direction.* By examining a number of data sets including data from the Low Energy Neutral Atom (LENA) on the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) and Magnetic Fields Investigation (MFI) on Wind, a team of GSFC investigators including M. Collier, T. Moore, D. Simpson, D.A. Roberts, A. Szabo and R. Lepping along with investigators from other institutions have proposed the controversial idea that there may be a secondary stream of energetic neutrals entering the heliosphere about 30° from the nominal upstream ecliptic longitude of 252° at about 282°.

*Investigation Into Two Competing Theories of Dust-Generated Neutral Solar Wind.* Using data from the LENA imager, which has made an instrumental contribution to the IMAGE spacecraft, a team of GSFC investigators including M. Collier, T.E. Moore, K. Ogilvie, D. Chornay, and J. Keller, along with investigators from other institutions has been examining dust-generated neutral solar wind to determine whether the dominant mechanism is charge exchange with neutrals evaporating from the grains or neutralization due to solar wind ions traversing the grains.

*Modeling of the Solar Corona.* E. Sittler, in collaboration with L. Ofman, J. Davila, M. Guhathakurta, S. Gibson, A. Fludra, R. Skoug and T. Holzer are developing an empirically constrained self-consistent 2D MHD model of the solar corona and solar wind. The model will produce 2D maps of flow density, velocity, temperature, magnetic field and model determined momentum addition due to waves. The self-consistent calculations use the energy equation with the empirically determined  $q_{eff}$  to constrain the solutions. They do not assume a polytrope. They also plan to use  $P_{eff}$  to constrain the momentum equation. When they only use  $q_{eff}$  the wind speed over the poles increases rapidly and then droops above 2 RS, which indicates that momentum addition by waves is required for high speed streams and argues for the need to add  $P_{eff}$  to the momentum equation. Both  $P_{eff}$  and  $q_{eff}$  are empirically determined by a 2D MHD model by E. Sittler and M. Guhathakurta. This model is not selfconsistent. The model is based on Mark III white light coronagraph data, Spartan white light coronagraph data and Ulysses plasma and magnetic field data and was acquired during solar minimum. They are also looking at data during the transition to solar maximum and are even considering solar maximum data, and evidence of three current sheets or helmut streamers resulting from the dominance of the octupole term for the Sun's magnetic field. Their self-consistent calculations also show a three current sheet topology. They also plan to add a recently developed heat conduction term in the energy equation and the inclusion of a parallel electric field (interplanetary potential) in the momentum equation.

*Cloud Structure.* The notion that a magnetic cloud may consist not of one but of a few closely interacting magnetic tubes came from the analysis of the relationship between the electron temperature  $T_e$  and the plasma density  $N_e$ . The log-log plot of  $T_e$  versus  $N_e$  for the June 10-13, 1993, Ulysses magnetic cloud revealed two polytropes that have been attributed by V.A. Osherovich, J. Fainberg, A. Figueroa-Viñas, and R. Fitzenreiter to two helices embedded in the same cylindrical flux rope. In contrast to configurations with cylindrical symmetry, magnetic configurations with helical symmetry allow a description of many helices which in cross section look like distorted flux ropes. They present elements of the magnetic and thermodynamic structure of the October 18-21, 1995, magnetic cloud observed by the Wind spacecraft. Their research complements previous studies of this cloud by others. The log-log plots

of  $T_e$  vs.  $N_e$  suggest that this cloud consists of eight magnetic tubes with polytropic indices below unity and a few non-coherent structures for which the polytropic relation is not valid. The solar wind quasi-invariant for this cloud strongly anti-correlates with the Dst index for the resulting magnetic storm.

*Solar Wind Quasi-invariant.* V. Osherovich and J. Fainberg continue to explore the variation of the solar wind quasi-invariant over distances of 2 to 27 AU using Voyager 2 data. Their results show that although B and Np decrease by orders of magnitude, QI as measured by Voyager 2 shows the same association with sunspot numbers (yearly values) as was found at 1 AU and at 0.7 AU.

*Modeling the Heliosphere in Three Dimensions.* A.V. Usmanov and M.L. Goldstein continue to develop a two-(axisymmetric) and three-dimensional MHD code and have incorporated an improved numerical algorithm (Total Variation Diminishing (TVD) Lax-Friedrichs with the Woodward limiter). They have also implemented a new algorithm to maintain the divergence-free constraint for the magnetic field. The two- and three-dimensional codes have been re-written with the Message Passing Interface (MPI) to take advantage of parallel computing environments. With these codes, the variation in solar wind magnetic field, density, velocity, and temperature observed during the first fast south-north transition of Ulysses have been modeled. A quadrupole has also been added to the solar surface magnetic field that allows us to investigate its effect on the solar wind plasma and magnetic field parameters. The simulated variations of plasma and magnetic field parameters showed good agreement with Ulysses observations.

*MHD Simulation of Large- and Intermediate-Scale Nonlinear Solar Wind Processes.* Spatial inhomogeneity and temporal variability near the Sun produce a highly nonuniform solar wind. Spacecraft studies show that this nonlinear medium is evolving and producing, for example, shocked stream interaction regions, turbulent cascades, and possible vortex streets. M. Goldstein and D.A. Roberts, working with A. Deane of the University of Maryland, are now performing 3-D MHD simulations of the solar wind in spherical geometry, including a wide variety of phenomena such as stream shear, wave, two-dimensional turbulence, microstreams, and magnetic pressure balance structures. The simulations now reproduce much of the observed behavior, such as strong spectral evolution near current sheets and shear layers and the formation of the expected interaction regions. New insights include the realization that nonlinear effects do not return either wave vectors or magnetic fields in the way required by some simple models of the fluctuations, and that the observed two-dimensional correlation function for interplanetary fluctuations can be reproduced by sheared waves in an expanding geometry. On the global scale, the simulations have revealed that it is difficult to keep the two heliospheric magnetic sectors separated, and that loop-like "connection" fields should be common. This conclusion is supported by Helios data

at heliospheric current sheet crossings. Much more complex patterns, supported by data analysis, result when a rotating current sheet is combined with shear and waves. The effects causing the connection field may be important for other phenomena, such as where rigidly rotating coronal holes are sheared by differential rotation.

*Solar Energetic Particles and Coronal Mass Ejections.* N. Gopalswamy, S. Yashiro, G. Michalek, M. Kaiser, R. Howard, D. Reames, Leske, and T. von Rosenvinge studied the association between Solar Energetic Particle (SEP) events and Coronal Mass Ejections (CME's) and found that CME interaction is an important aspect of SEP production. Each SEP event was associated with a primary CME that is faster and wider than average CME's and originated from west of E45. For most of the SEP events, the primary CME overtakes one or more slower CME's within a heliocentric distance of  $\sim 20$  solar radii. In an inverse study, they found that for all the fast (speed  $> 900$  km/s) and wide (width  $> 60$  deg) western hemispheric frontside CME's during the study period, the SEP-associated CME's were  $\sim 4$  times more likely to be preceded by CME interaction than the SEP-poor CME's, i.e., CME interaction is a good discriminator between SEP-poor and SEP-associated CME's. They infer that the efficiency of the CME-driven shocks is enhanced as they propagate through the preceding CME's and that they accelerate SEPs from the material of the preceding CME's rather than from the quiet solar wind. They also found a high degree of association between major SEP events and interplanetary type II radio bursts suggesting that proton accelerators are also good electron accelerators. The fast and wide CME's without SEPs were all found to be ejected into a very tenuous corona.

*CME Interaction and Nonthermal Radio Emission.* N. Gopalswamy, S. Yashiro, M. Kaiser, R. Howard, and J.-L. Bougeret reported the detection of a new class of nonthermal radio emission due to the interaction between two CME's. The radio emission was detected by the Radio and Plasma Wave Experiment (WAVES) on board the Wind satellite, while the CME's were observed by the white-light coronagraphs of the Solar and Heliospheric Observatory (SOHO) mission. There was no type II radio burst (metric or interplanetary) preceding the nonthermal emission. The radio emission occurred at a distance beyond 10 solar radii from the Sun, where the two CME's came in contact. Using H-alpha and EUV images, they found that the two CME's were ejected roughly along the same path. They argue that the nonthermal electrons responsible for the new type of radio emission were accelerated due to reconnection between the two CME's and/or due to the formation of a new shock at the time of the collision between the two CME's.

*Interplanetary Radio Emission and CME's.* N. Gopalswamy, S. Yashiro, M. Kaiser, R. Howard, and J.-L. Bougeret investigated the characteristics of CME's associated with long wavelength type II radio bursts in the near-Sun interplanetary medium. Type II radio

bursts in the decameter-hectometric (DH) wavelengths indicate powerful MHD shocks leaving the inner solar corona and entering the interplanetary medium. Almost all of these bursts are associated with wider- and faster-than-average CME's. A large fraction of these radio-rich CME's were found to decelerate in the coronagraph field of view, in contrast to the prevailing view that most CME's display either constant acceleration or constant speed. They found a similar deceleration for the fast CME's (speed  $> 900$  km/s) in general. They suggest that the coronal drag could be responsible for the deceleration, based on the result that the deceleration has a quadratic dependence on the CME speed. About 60% of the fast CME's were not associated with DH type II bursts, suggesting that some additional condition needs to be satisfied to be radio-rich. The average width ( $66^\circ$ ) of the radio-poor, fast CME's is much smaller than that ( $102^\circ$ ) of the radio-rich CME's, suggesting that the CME width plays an important role. The special characteristics of the radio-rich CME's suggest that the detection of DH radio bursts may provide a useful tool in identifying the population of geoeffective CME's.

*Space Weather Application.* N. Gopalswamy, A. Lara, S. Yashiro, M. Kaiser, and R. Howard have developed an empirical model to predict the 1-AU arrival of CME's. This model is based on an effective interplanetary (IP) acceleration that the CME's are subject to, as they propagate from the Sun to 1 AU. This model has been improved (i) by minimizing the projection effects (using data from spacecraft in quadrature) in determining the initial speed of CME's, and (ii) by allowing for the cessation of the interplanetary acceleration before 1 AU. The resulting effective IP acceleration was higher in magnitude than what was obtained from CME measurements from spacecraft along the Sun-Earth line. The predictive capability of the CME arrival model was estimated using recent two-point measurements from the SOHO, Wind and ACE spacecraft. They found that an acceleration cessation distance of 0.76 AU is in reasonable agreement with the observations. The new prediction model reduces the average prediction error from 15.4 to 10.7 hrs. The model is in good agreement with the observations for high speed CME's. For slow CME's, the model as well as observations show a flat arrival time of  $\sim 4.3$  days. Use of quadrature observations minimized the projection effects naturally without the need to assume the width of the CME's. However, there is no simple way of estimating the projection effects based on the surface location of the Earth-directed CME's observed by a spacecraft (such as SOHO) located along the Sun-Earth line because it is impossible to measure the width of these CME's. The standard assumption that the CME is a rigid cone may not be correct. In fact, the predicted arrival times have a better agreement with the observed arrival times when no projection correction is applied to the SOHO CME measurements. The results presented in this work suggest that CME's expand and accelerate near the Sun (inside 0.7 AU) more than their model supposes; these aspects will have to be included

in future models.

*Living with a Star (LWS) Coordinated Data Analysis Workshop (CDAW).* N. Gopalswamy and B. Thompson organized the LWS/CDAW on SEPs during July 22-26, 2002, near GSFC. The goal of the workshop was to enable and enhance the science return from a number of recent/existing space missions such as Wind, ACE, SOHO, IMP-8, Yohkoh, and Ulysses. Imaging and Time series data on all aspects of the SEP events that occurred during solar cycle 23 between January 1996 and December 2001 were gathered to be analyzed by scientists from various communities dealing with Sun-Earth connection. There were 48 events in all, which were analyzed to study the solar origins, SEP physics, and Geospace impact of these particle events. First-cut results are being prepared to communicate to Geophysical Research Letters as a special section.

*Magnetic Fields and Flows in the Distant Heliosphere.* Voyager 1 and 2 observations show that the global structure of the heliospheric magnetic field strength and direction continues to be described accurately by the spiral field model of Parker out to 87 AU. The radial evolution of the magnetic field strength fluctuations observed by ACE during 1999 was modeled out to 60 AU. A Global Merged Interaction Region (GMIR) began to form at 15 AU and was fully developed at 60 AU. Small scale fluctuations in B diminished with increasing distance from the Sun. The GMIR reached Voyager 1 and Voyager 2 in mid-2000, and it caused a major step-decrease in the cosmic ray intensity. The corresponding radial evolution of the speed fluctuations from 1 to 60 AU was modeled and shown to be consistent with the Voyager 2 observations. A relationship between the speed and temperature outside AU at all latitudes was found by Y.C. Whang and L. Burlaga, and this was used to predict that Voyager 1 is possibly within several AU of the termination shock. The magnetic fields and flows produced by the Bastille Day flare were observed at Voyager 2. The radial evolution of this flow system was modeled, and the predicted structure at 60 AU was in agreement with the observed structure.

*Ejecta, CME's and Transitory Corotating Streams at 1 AU.* When successive CME's are ejected earthward from the Sun, they can interact and merge to form flows called 'complex ejecta' which lose memory of the detailed structure of the original flows as the result of interactions. This implies that the traditional assumption of a one to one correspondence between interplanetary ejecta and CME's is not valid, and demonstrates the need for new observational and theoretical studies of the evolution of CME's. Corotating streams are usually assumed to be stationary, but transitory corotating streams do exist as recently shown by Burlaga's group, the cause and the implications for the structure of the interplanetary magnetic field remain to be explored.

*Large-scale Fluctuations of the Speed at 1 AU.* The methods of turbulence theory, and the study of distribution functions of speed fluctuations in particular, have been used to provide a statistical description of the mul-

tiscale structure of the speed fluctuations at 1 AU by Burlaga's group. This approach provides initial conditions for a new way to study the evolution of flows and magnetic fields in the heliosphere, without requiring radial alignments of spacecraft, which are very rare.

*Solar Radio Bursts.* T. Golla and R.J. MacDowall have investigated various aspects of the interplanetary extensions of solar radio bursts. Type II radio emission, produced by electrons from coronal or interplanetary shocks, is frequently observed to be highly fragmented. Mechanisms involving mode conversion at sharp gradients in density were examined and found likely to contribute to fragmented emissions. An unusual wave event at 5 AU was determined to provide evidence of electrostatic decay of the Langmuir waves.

## 7 SPACE SCIENCE MISSIONS AND MODELING: OPERATIONAL

### 7.1 Mars Odyssey 2001

*Gamma-Ray Spectrometer (GRS) and High Energy Neutron Detector (HEND).* J. Trombka is involved as Co-investigator and Participating Scientist on the Mars Odyssey 2001 GRS and HEND experiment. This is a re-flight of the GRS that was part of the instrument complement on the Mars Observer mission that was lost in August 1993. The Mars Odyssey spacecraft was launched in April 2001, arrived at Mars in October 2001, and began mapping the surface of the planet in February 2002. The GRS is really an instrument suite consisting of the GRS, a Neutron Spectrometer (NS) and a HEND. Each of these instruments/sensors are remotely mounted at different locations on the spacecraft and connect to a central electronics box. The GRS will achieve global mapping of the elemental composition of the surface and the abundance of hydrogen in the shallow subsurface. The Principal Investigator is W. Boynton of the University of Arizona.

During the first few months of observations the GRS identified two regions near the poles that are enriched in hydrogen. The data indicate the presence of a subsurface layer enriched in hydrogen overlain by a hydrogen-poor layer. The thickness of the upper layer decreases with decreasing distance to the pole, ranging from a column density of about 150 g/cm<sup>2</sup> at -42° latitude to about 40 g/cm<sup>2</sup> at -77°. The hydrogen-rich regions correlate with regions of predicted ice stability. An ice abundance of 35% ± 15% by weight, is the most likely host of the hydrogen in the subsurface layer.

### 7.2 CLUSTER II

*Plasma Electron and Current Experiment (PEACE), Electric Field and Waves, and Magnetometer.* The four spacecraft that comprise the ESA/NASA Cluster mission continue to operate nominally. The main goal of Cluster is to study small-scale three-dimensional plasma structures in key plasma regions such as the solar wind, bow shock, magnetopause, polar cusps, magnetotail and auroral zones, taking advantage of the spacecraft's con-

trolled formation. Cluster’s payload comprises state-of-the-art plasma instrumentation to measure electric and magnetic fields from quasi-static up to high frequencies, and electron and ion distribution functions from energies of nearly 0 eV to a few MeV. The science operations are coordinated by the Joint Science Operations Centre, JSOC, at the Rutherford Appleton Laboratory (UK), and implemented by the European Space Operations Centre, ESOC, in Darmstadt, Germany. A network of eight national data centers, including the US node accessible via the CDAWeb interface at the NSSDC at GSFC, has been set up for raw data processing, the production of physical parameters, and their distribution to end users all over the world. Data from PEACE (M.L. Goldstein, NASA Lead Co-investigator) has recently been made accessible to the public via a web interface developed at Southwest Research Institute under the direction of D. Winningham (see, <http://cluster2.space.swri.edu>). The Laboratory for Extraterrestrial Physics made significant contributions to several of the experiments, including, the PEACE (A. Fazakerley, Mullard Space Science Laboratory, Principal Investigator) and the Electric Fields and Waves (M. Andre, Swedish Institute of Space Physics). The flight hardware for the magnetometer (A. Balogh, Imperial College, United Kingdom) was designed and fabricated at several institutions with LEP providing the magnetometer sensors and analogue electronics. M. Acuña, D. Fairfield, and J. Slavin are the LEP magnetometer Co-investigators and they will participate actively in the data analysis effort. Initial investigations of magnetic flux ropes in the near-earth plasma sheet have used the curlometer technique to reveal clear departures from the generally assumed force-free (i.e.,  $J \times B \sim 0$ ) condition within these structures.

### 7.3 IMP-8

*Magnetic Field Investigation (MAG).* Fall 2002 marks the 29th anniversary of IMP-8’s operations. The spacecraft has provided valuable solar wind, magnetosheath and magnetospheric field and particle data over its long lifetime. The magnetometer (A. Szabo, Principal Investigator) suffered an anomaly on June 10, 2000, preventing the collection of useful data. Analysis of the anomaly and corrective measures continues. The 15.36s time resolution magnetic field data has been updated for the entire mission and placed on line via the publicly available CDAWeb. Also, the highest time resolution (320 msec) data set for the entire mission is currently being reprocessed to facilitate faster and easier public dissemination of this data. On-campus Co-investigators of this experiment are R.P. Lepping and J.A. Slavin, while an off campus Co-investigator is N. Ness at the Bartol Research Institute, University of Delaware.

### 7.4 Wind

*Wind Proposal.* At the April 2002 senior review, a decision was taken to relegate Wind to being a “hot spare” for ACE. K. Ogilvie drafted and presented a more constructive alternative proposal to NASA Headquar-

ters. This calls for Wind to enter a large halo orbit about L1, performing well-defined science campaigns in collaboration with other spacecraft. Several of these are presently in progress. The data system is being revised and Level-Zero data and key parameters will be available to all. This work has been a large collaborative effort.

*Wind electron instrument modification.* The SWE instrument on the Wind spacecraft consists of two parts, VEIS and Strahl. The detector bias supply on VEIS recently failed. K. Ogilvie and J. Needel (University of New Hampshire) have turned VEIS off, given its resources to Strahl, and reconfigured Strahl to perform many of the things previously done with VEIS.

*Wind Magnetic Field Investigation (MFI) Health and Status.* The Wind MFI magnetometer system continues to function nominally. Most of the mission data set is publicly available both as rapidly generated Key Parameter (KP) data and as final calibrated data, including 1-hour averages, 1-min averages, and higher time resolution (3 sec) data from the team’s web site and the Space Physics Data Facility’s CDAWeb. In addition, added value support data, such as bow shock crossing times, lists of magnetic clouds and interplanetary shocks are constantly updated on the team’s web site. The very highest (msec) time resolution data continues to be distributed on an individual request basis. Some of the team’s research areas are studies of the properties of the interplanetary medium (e.g., shock waves, directional discontinuities especially in comparison with IMP-8 observations, and large quasi-static and transient events, especially magnetic clouds and the heliospheric current sheet), their comparisons to solar events, the magnetosphere’s boundaries, and magnetotail events during active periods. MFI’s website also contains a bibliography of about 190 Wind articles and papers on which a team member is either author or co-author. The Laboratories’ members of the MFI team are M. Acuña, L. Burlaga, M. Collier, W. Farrell, R. Kennon, R. Lepping (Principal Investigator), J. Scheifele, J. Slavin, A. Szabo (Data Production Manager), and E. Worley, as well as four off-campus members.

### 7.5 IMAGE

*Program Management.* T. Moore continued as Project Scientist for the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) mission as it operated through its second year in orbit and beyond. IMAGE was highly rated by the senior review of operating missions, and was designated for an extended mission into FY93-95 (albeit at a funding level lower than what was considered sufficient for “bare-bones” operations by the science team). During early May of 2002, observations from IMAGE were the subject of a NASA Space Science Update for the media, entitled “Protection at a price from Earth’s Space Storm Shield,” which refers to the participation of Earth’s atmosphere as an ablative absorber of energy in space storms. The IMAGE spacecraft and all instruments continue to perform outstandingly well into the third year of opera-

tions, supporting a high rate of science results publication (<http://image.gsfc.nasa.gov/publication/>). A workshop on IMAGE early results was held in February 2002, and the invited papers are being edited into a monograph to be published in early 2003.

*Low Energy Neutral Atom Imager (LENA).* The science investigation of LENA data, led by T.E. Moore, have continued to elucidate the prompt enhancements in the outflow of ionospheric plasma from the Earth, in response to solar wind enhancements. The component of neutral atoms in the solar wind has provided an indirect remote measurement of the presence of gases and dust in the inner solar system. Recently, attention has focused on a  $\sim 30^\circ$  tilt between the direction of maximal solar wind neutral flux and the direction of interstellar neutral wind. In addition, LENA directly observed the interstellar neutral gas in the region downstream of the sun during a second winter season.

*Magnetospheric Radio Sounding.* R. Benson, J. Fainberg, and colleagues at GSFC have developed techniques to aid in the interpretation of plasma resonances stimulated by the Radio Plasma Imager (RPI) on the IMAGE satellite. Working with RPI Principal Investigator B.W. Reinisch and colleagues at the University of Massachusetts, Lowell, these resonances are used in the determination of magnetospheric electron-density profiles and the in-situ electron density and magnetic-field strength along the IMAGE orbit.

*Ring Current - Neutral Atom Modeling in Support of the IMAGE mission.* Energetic ion fluxes and the associated Energetic Neutral Atom (ENA) images are simulated during active periods since the launch of the IMAGE mission. These modeled results help researchers understand and interpret the features seen by the IMAGE/ENA instruments. Recent images of the ring current from the High Energy Neutral Atom (HENA) imager revealed strong enhancements in the post-midnight sector during storm main phases, contradicting the traditional picture of ring current intensification at dusk. Simulations carried out with the Comprehensive Ring Current Model by M.-C. Fok showed remarkably good agreement with the HENA data. Preliminary analysis shows that magnetosphere-ionosphere coupling plays an important role in the formation of these post-midnight enhancements. A web site (<http://mcf.gsfc.nasa.gov/IMAGE/>) has been developed to display these results for the use of the IMAGE team and the broader space science community.

## 7.6 CASSINI

*Cassini Plasma Spectrometer (CAPS).* E. Sittler is a Co-investigator for the CAPS instrument. CAPS is composed of five major subsystems. As Co-investigator for CAPS, E. Sittler has been in charge of development of certain flight software and scientific analysis of CAPS data at GSFC. E. Sittler developed a high speed algorithm which de-convolves the TOF spectra accumulated in the Spectrum Analyzer Module (SAM) which was also developed at GSFC. They are now involved in a major

upgrade of the flight software as required by the CAPS team. In order to test the flight software they have an engineering model of the CPU1, CPU2, and SAM boards with a Time-to-Digital Converter (TDC) simulator. This equipment also includes GSE and Tartan Ada compiler and simulation software on a Sun workstation. Parts of this hardware system are being upgraded. They are also developing a SAM Group Table Generation System which will automate the production of Group tables from calibration data. The Group Tables are a list of numbers that configure the SAM software to do its analysis of the coincidence data from the Ion Mass Spectrometer (IMS). They are in the process of developing a simulation code which takes into account the spacecraft trajectory through Saturn's magnetosphere and spacecraft attitude, uses the latest plasma and magnetic field models of Saturn's magnetosphere, assumes bi-Maxwellians for the ions, and models the IMS response function to generate simulated data.

*Cassini Radio and Plasma Wave System (RPWS).* M. Kaiser, M. Desch, and W. Farrell continue the analysis of the Cassini RPWS measurements from the Cassini/Jupiter flyby in January 01. The team has been involved in a number of papers including submissions to the Nature special issue highlighting the encounter. Currently, team members are correlating possible Saturnian radio events with projected solar wind dynamic pressure in preparation for the 2004 Saturn tour.

*Cassini Composite InfraRed Spectrometer (CIRS).* A major effort has continued for the Cassini CIRS experiment. A theoretical basis for estimating damage to the instrument foreoptics by collisions with micrometer-sized particles in the Saturnian environment has been derived. Observations of Jupiter and of stellar sources have been obtained and applied to the determination of the spatial response of the instrument's three focal planes. Planning of observations for the four-year orbital tour of Saturn that begins in 2004 continues.

## 7.7 Voyager 1 and 2

*Voyager 1 and 2 Magnetometers.* The magnetometers on Voyagers 1 and 2 continue to function as designed and return data from unexplored regions of the distant heliosphere. They are now approaching the termination shock and heliosheath. Voyager 1 is now at 86 AU at a latitude of  $34.6^\circ$ N and Voyager 2 is at 68 AU at a latitude of  $27.8^\circ$ S. L. Burlaga is responsible for the reduction of the data and actively analyzes these data.

## 7.8 Polar

*Project Management.* The Polar spacecraft continues to operate with 12 of the 13 instruments. The 9 Re apogee of the polar orbit, which started high over the northern polar region, just precessed across the equator, yielding new data by skimming the dayside magnetopause during the spring period and crossing the plasmasheet in the tail during the fall period. A strategy for use of the remaining fuel on board for spin direction control has switched the spin axis between orbit nor-

mal and ecliptic normal. An orbit normal attitude will now be maintained until late 2003, after which ecliptic normal operations will be continuous until all fuel is exhausted sometime in 2005. The last orbit normal operations will yield increasing observations of the southern auroral oval. During this past year the data processing for Polar, Wind, and Geotail has been re-engineered to a new system (<http://pwg.gsfc.nasa.gov>). The old CDHF of the ISTP program was turned off on October 1. R. Hoffman is the Polar Project Scientist and B. Giles the Deputy.

*Thermal Ion Dynamics Experiment-Plasma Source Instrument (TIDE-PSI).* A team led by T.E. Moore studied topics ranging from the entry of solar wind plasma into the magnetosphere through the cusp region, to the outflow of ionospheric plasma as influenced by solar wind conditions, to the global transport of plasmas throughout the magnetosphere accessible to Polar. This work involved extensive collaboration with investigators on other ISTP spacecraft, notably Wind, the Fast Auroral Snapshot Explorer (FAST), and the LANL geosynchronous spacecraft, but also DMSP, Interball, amongst others; and is continuing through the next solar maximum period in a few years.

## 7.9 Ulysses

*Unified Radio and Plasma (URAP) Wave and Solar Wind Ion Composition Spectrometer (SWICS).* As of September 2002, the Ulysses spacecraft was well into its second “slow” latitude scan, at a distance of 4 AU from the Sun and a heliographic latitude of approximately  $30^\circ$ . At this point in space, the spacecraft was intercepting corotating interaction regions, which had disappeared during the peak of solar activity. The Ulysses trajectory is carrying towards Jupiter and a variety of Jovian radio emissions are detected routinely; permitting correlative studies with Cassini. Ulysses will approach to within about 0.8 AU of the planet, permitting extensive radio studies to be undertaken. Due to its highly inclined orbit, the spacecraft will reach a jovigraphic latitude of  $75^\circ$ , providing a unique perspective of Jovian radio emissions, which are highly latitude dependent. These observations will be correlated with other space-based (Chandra, Hubble Space Telescope) and Ground-based observations of Jovian auroral zones. The GSFC contributions to Ulysses include involvement with two of its instruments: the URAP and the SWICS. URAP Co-investigators are M. Desch, J. Fainberg, M. Goldstein, M. Kaiser, R.J. MacDowall (Principal Investigator), M. Reiner, and R. Stone (Principal Investigator Emeritus); K. Ogilvie is an unfunded Co-investigator on the SWICS team.

## 7.10 Fast Auroral Snapshot Explorer (FAST)

NASA’s FAST satellite continues to acquire excellent data and provides an exciting new look on acceleration processes at the interface of the hot, magnetospheric plasma and the cool, ionospheric plasma. The FAST science team has already reported several major

discoveries. Instruments on FAST include fast energetic electron and ion spectrometers, vector DC and AC electric and magnetic field detectors, and an energetic ion composition instrument. The Principal Investigator for FAST is C.W. Carlson of the University of California, Berkeley. R. Pfaff is the NASA Project Scientist for the FAST mission.

## 7.11 Communications/Navigation Outage Forecast System (C/NOFS)

Goddard’s Vector Electric Field Investigation (VEFI) is being prepared for inclusion on the Air Force C/NOFS satellite to be launched in late 2003. The main objective of the satellite is to study irregularities in the equatorial ionosphere that disrupt communications and navigation systems. Such irregularities are generally associated with equatorial “spread-F” and are linked to ionospheric plasma depletions and variable DC and AC electric fields. The planned orbit of the C/NOFS satellite is 400 by 700 km with a 13 degree inclination. The VEFI experiment includes instrumentation to measure DC and AC electric fields, and includes a burst memory, on-board signal processing (FFTs), and a filter bank. In addition, the VEFI experiment also includes a magnetometer (to be provided by M. Acuña, a lightning detector, and a fixed-bias Langmuir probe which serves as the trigger input for the burst memory. R. Pfaff is the Principal Investigator of the VEFI instrument for C/NOFS.

## 8 COMMUNITY COORDINATE MODELING CENTER (CCMC)

The CCMC is an inter-agency activity, led by M. Hesse, aiming at research in support of the generation of advanced space weather models. CCMC’s central facility is located within the Laboratory of Extraterrestrial Physics. New and improved space research models will be created by combining models and modules. Models and modules will be developed mostly in the scientific community, but also at the CCMC GSFC facility itself if required. The ultimate goal of the CCMC is the generation of a flexible chain of comprehensive space weather models, which cover the entire range from the solar corona to the Earth’s upper atmosphere. Combined models will have switchable modules, covering different regions and different physics. Models, which have been developed and passed metrics-based evaluations and science-based validations will be handed off to the Rapid Prototyping Centers of NOAA and the Air Force, for operational testing. These models are also available to the scientific community for runs-on-request, to support the “open model policy.” CCMC has now tested the University of Michigan global MHD model, which features dramatically increased numerical stability, and which is now used routinely. CCMC staff has coupled this model with a radiation belt model, developed at GSFC. Results from the CCMC simulations are available on-line, at the CCMC web page (<http://ccmc.gsfc.nasa.gov>). The CCMC web site provides, to the scientific community, an advanced interface

for the scientific analysis of CCMC model runs. CCMC has handed off to the AF RPC two models. CCMC is also in the process of ingesting additional ionospheric and solar models.

## 9 INSTRUMENT DEVELOPMENT

*Linear Etalon Imaging Spectral Array (LEISA) Development.* D. Reuter, D. Jennings and G. McCabe are developing infrared spectral imagers based on the LEISA concept. This development is a collaboration with members of the Engineering Directorate. LEISA represents a completely new concept in spectrometer design made possible by large-format detectors and advances in thin-film technology. Originally developed for the Pluto Fast-Flyby Mission (PFF) under the Advanced Technology Insertion Program, LEISA uses a state-of-the art filter (a Linear Variable Etalon (LVE)) in conjunction with a detector array to obtain spectral images. The major innovation of LEISA is its focal plane which is formed by placing a LVE in very close proximity to a two-dimensional detector array. The LVE is a wedged dielectric film etalon whose transmission wavelength varies along one dimension. In operation, a two-dimensional spatial image is formed on the array, with varying spectral information in one of the dimensions. The image is formed by an external optic. Each spatial point is scanned in wavelength across the array, thereby creating a two-dimensional spectral map. Scanning may be accomplished by a number of methods such as by the orbital motion of the spacecraft, by rotating the spacecraft, as was planned for PFF, or by a steerable mirror. The actual spatial resolution is determined by the spatial resolution of the imaging optic, the image scan speed, and the readout rate of the array. The spectrometer has no moving parts, a minimum of optical elements and only one electronically activated element, the array. Compared to conventional grating, prism, or Fourier transform spectrometers and mechanically or electrically tunable filter systems, it represents a great reduction in optical and mechanical complexity.

The LEISA/Atmospheric Corrector (LAC) is on the New Millennium Program Earth Orbiter 1 (EO-1) mission launched in November of 2000. This camera provides 250 meter spatial resolution, 0.89 to 1.6  $\mu\text{m}$  spectral images at a constant spectral resolution of  $\sim 40 \text{ cm}^{-1}$ . The primary purpose of this atmospheric data is to correct the high spatial resolution, low spectral resolution Landsat-type multispectral images (from another instrument on-board) for the spatially and temporally variable effects of the atmosphere. EO-1 flies in formation with the operational Landsat-7 satellite which allows the operational Landsat data to be corrected as well. Atmospheric correction is expected to improve the accuracy of satellite measured surface reflectances and increase the reliability of data products derived from them. The unique hyperspectral images also provide scientific data in their own right, including water vapor estimates, cloud and aerosol parameters, and surface properties. Another LEISA variant will provide shortwave in-

frared (1.25 to 2.5  $\mu\text{m}$ ) spectral images of Pluto as one of the prime instruments aboard the New Horizons mission. In this mission, to be launched in 2006 and reach Pluto in the 2015 time frame, a LEISA sensor will be used to obtain composition measurements of Pluto and Charon at resolutions as fine as 2 km. During the 5 to 10 years following that encounter, one or more other Kuiper Belt Objects (KBOs) will be observed as well. LEISA flew as one of the major scientific instruments on the TRW Small Satellite Technology Program (SSTP) satellite, Lewis launched in August of 1997. Unfortunately, this satellite re-entered prematurely in September, 1997 before any data were obtained. LEISA-based instruments were included in proposed Venus and Mercury Discovery missions. In addition to these satellite programs LEISA has flown in an aircraft in the summers of 1997, 1998, and 1999 as part of the instrument complement in an agricultural sensor program. The flights were over agricultural areas near Lubbock, Texas. The purpose of the program was to transfer GSFC developed technology to the commercial sector and to develop software to perform atmospheric correction of remotely sensed, high-spatial resolution, multispectral VNIR measurements. This activity was part of a Space Act Agreement with Boeing Commercial Space Company. The airborne LEISA instrument was also flown in South Africa in March of 1999 as part of the ARREX program.

*Acousto-optic Imaging Spectrometer (AIMS).* A compact, two-channel (VIS/short-wave IR) Acousto-Optic Tunable Filter (AOTF) camera has been built at GSFC, with support from the Office of Space Science, Mars Instrument Development Project (MIDP). Principal Investigator is D. Glenar and other team members include D. Blaney (JPL), D. Britt (University of Tennessee), T. Roush (NASA/AMES), T. Flatley (GSFC) and A. Vizzini (University of Maryland). AIMS is an electronically tunable, multispectral camera which operates from 0.48 to 2.4  $\mu\text{m}$ . It can rapidly identify and map key mineralogical units at a Mars landing site. These measurements have been given high priority in the list of investigation themes established by the Mars Exploration Payload Advisory Group (MEPAG). A new proposal has been submitted to MIDP to: (i) complete the calibration of AIMS, (ii) retrofit the short wavelength (0.5-1.0  $\mu\text{m}$ ) channel with a hybrid focal plane in order to reduce power and extend the wavelength overlap with the IR channel, and (iii) conduct field tests at NASA/AMES.

*Planetary Bolometers and Spectrometers.* J. Brasunas, in concert with B. Lakew, R. Fettig and S. Aslam, has continued the development of moderately cooled infrared bolometers based on thin-films of the High Temperature Superconductor (HTS) materials YBCO and GdBCO. In addition to the bolometer work, J. Brasunas is pursuing development of very broad-band, visible-to-millimeter wavelength beamsplitters based on free-standing, grown films of Chemical Vapor Deposition (CVD) diamond. A vendor has been located with the ability to improve the surface flatness by a process of magnetorheological fluid polishing. By combining the

bolometer and the CVD beamsplitter, the goal is to produce HTSFTS, a smaller, lighter version of the CIRS spectrometer for future planetary missions. Discussions have commenced with E. Sittler to place HTSFTS on the Titan Orbiter Aerover Mission (TOAM), nominally planned for the second round of the New Frontiers program.

*Gold Black Deposition Facility.* For the deposition of gold black (a fractal conglomeration of nano-particles) a facility is maintained and further developed by R. Fetting in collaboration with J. Brasunas and B. Lakew. Gold black can be used as an absorber of low heat capacity for radiation from visible wavelength all the way through the infrared, into the submillimeter range. It is applied to HTS bolometers.

*MgB<sub>2</sub> Investigations.* Study of magnesium diboride (MgB<sub>2</sub>) for possible use as the sensing element in Far IR bolometers has been started this year by the Planetary Systems Branch detector development group. MgB<sub>2</sub> exhibits superconducting properties around 39 K. Thin films deposited via Pulsed Laser Deposition (PLD) on sapphire substrates were cooled to the mid-point of their transition temperature. Noise data was obtained on these films. Preliminary results show higher than expected noise levels. Possible causes are oxygen contamination as well as loss of Mg from the film. Improvements to the deposition process as well as Mg encapsulation are planned. B. Lakew is the Principal Investigator and J. Brasunas a Co-investigator. The University of Maryland Center for Superconductivity Research is a partner.

*Far IR Imaging Array.* The effort to develop a 2-D array of HTS bolometers on monolithic sapphire membranes has continued. A mask that withstands the etching process has been successfully developed. However the mask removal process has caused pits to form on the sapphire membranes' surface. Work is under way to solve this final hurdle. Each pixel's sensing element is expected to be either YBCO, or GdBCO. R. B. Lakew is the Principal Investigator, with J. Brasunas, I. Aslam, and R. Fetting as Co-investigators.

J. Trombka's group is involved in the development of advanced detectors to be used with remote sensing XGRS systems. Two programs in which significant progress has been achieved are discussed. Gamma-ray spectroscopy has been used by orbital spacecraft and landed missions to determine the surface elemental abundances of planetary surfaces. The next logical step for planetary exploration is to include a GRS on a rover, but such an instrument must be light-weight, compact, and low-power because of the severe mass and power restrictions common to such missions. An instrument development team at Goddard has begun work with CdWO<sub>4</sub> (CWO) scintillators. This is a relatively new scintillation material has a high Z and high density which is a requirement for gamma-ray spectrometers. Coupled to photomultiplier tubes, CWO can achieve excellent energy resolution compared to other scintillators. Their radiation resistance and poorer detector activation of interfering

lines show great promise for space flight application.

Schottky CdTe(Cl) type x-ray and gamma-ray detectors have attracted a lot of attention in the last several years. The reported spectral characteristics for detectors of thickness up to 1mm operated at -200C show excellent energy resolution and peak to valley ratios. The improved results are due to the production of homogeneous large volume single crystals. Schottky CdTe(Cl) detectors may be considered for use in interplanetary missions, which typically require long cruise periods of several years before reaching the intended target. One important requirement is the stability of the detector against the radiation of high energy protons. During missions the detectors are exposed to cosmic ray protons with a mean energy near 1GeV and solar flare protons with a mean energy around 100 MeV. Workers at GSFC have begun testing the radiation susceptibility of these detectors.

*Heterodyne Instrument for Planetary Wind And Composition (HIPWAC) Instrument Development.* The new HIPWAC has now been used on four observing runs at the NASA IRTF in December 2000, February 2001, August 2001, and August 2002, successfully meeting the scientific objectives of each run. HIPWAC is an advanced Infrared Heterodyne Spectrometer (IRHS) for the measurement of molecular lineshapes and the wind-driven Doppler shifts of molecular lines formed in low-pressure, high altitude, regions of planetary atmospheres. HIPWAC development activities continue to include upgrading the optics, expanding remote control capabilities, upgrading the calibration and stabilization systems, improving the back end electronics, and refitting the instrument for operation on the Gemini 8m telescope facilities. The HIPWAC effort is led by T. Kostiuik, with J. Annen, D. Buhl and K. Fast, T. Livengood and J. Goldstein, and T. Hewagama. Design support and CAD drafting has been provided by P. Rozmarynowski and F. Hunsaker. Mechanical engineering and composite-materials fabrication of the HIPWAC optical benches, optical mounts, and laser cavities was provided by K. Segal and P. Blake. Student J. Delgado (University of Maryland) characterized optical components and subsystems in the laboratory and was able to attend and significantly contribute to the third observing run. Improved performance of HIPWAC derives from implementation of new technologies and from the characteristics of large (8-10m) telescopes accessible to a transportable instrument: (1) factor of ~10 improvement in sensitivity on small targets compared to a 3m telescope; (2) improved spatial discrimination; (3) reduced velocity broadening due to range of Doppler shift from planetary rotation across the diffraction-limited FOV; (4) improved system quantum efficiency compared to current components; (5) flexible access to available telescopes; and (6) access to different latitudes from which to observe. The prototype 1 meter-length cavity for the CO<sub>2</sub> laser local oscillator was used in the December 2000 and February 2001 runs. The advanced dual-laser-tube cavity supporting 0.5m tubes was used in August 200 and 2002. The

IRHS group presently is investigating the replacement of old discrete RF filter technology for signal processing with a modern acousto-optic spectrometer system. Work is continuing on an overall upgrade to mate HIP-WAC to any of the general class of 8-10m telescopes now in operation and to improve data acquisition software.

*Omni-directional Low Energy Geoplasma (OLEG) Camera Development.* A team from the Laboratory for Extraterrestrial Physics including M. Collier, T.E. Moore, D. Chornay, J. Keller and P. Rozmarynowski along with additional investigators from Russia and MSFC have developed a working laboratory prototype of an ultra-fast all-sky imager of the plasma velocity distribution that leaves only particle energy to be swept electrostatically. This instrument, called the OLEG Camera, uses electrostatic mirrors in compound curved geometries to map spherical polar angle into radius and spherical azimuth into azimuth onto a circular imaging detector system.

*Measuring the Solar Wind Near the Sun.* E. Sittler has led the development of nadir viewing technology for solar wind ions-electrons for the Solar Probe Mission. Most of the work has concentrated on the thermal input to the spacecraft and the mechanical design of the booms. Development of high temperature thermal blankets has reduced the thermal input to the spacecraft bus to less than a few watts. They are now in the process of considering a design concept that will not need the use of booms and thus simplifies the present design. This technology will allow measurements of the solar wind ions-electrons all the way to perihelion which is only 4 solar radii from Sun center. The electrostatic mirrors are now projected to operate below 50°C which is considerably cooler than earlier projections. The electrostatic mirrors are composed of parabolically shaped wire meshes. We have also been investigating various coating techniques which will “solder” the wire mesh into the desired shape. Problems have occurred when the mirror is flat and wrinkles tend to form. This is believed to be caused by thermal expansion and contraction of the mandrel made of delrin during the plating process. One solution to be investigated is using materials with low thermal expansion coefficient and coated with Teflon; the Teflon is needed so that the wire mesh does not bond to the mandrel during the plating process. Another approach is to use a photo-etching technique and does not have the thermal expansion problems noted above. They also plan to improve the optical design of the mirrors. This will then be followed up by ion beam calibration measurements.

*Miniaturized Plasmas Analyzers.* T.E. Moore, M. Collier and J. Lobell been developing miniaturized analyzers for plasmas, appropriate to multi-spacecraft missions such as Magnetospheric MultiScale Mission (MMM) and Magnetospheric Constellation Mission (MCM). In addition, reduction in size of more traditional “top-hat” analyzers has been undertaken as a combined mechanical engineering-packaging-machining challenge, in collaboration with the Engineering Directorate of GSFC. A dedicated ASIC solution for sweep co-

ordination and data acquisition is being developed, also in collaboration with M.A. Johnson. Finally, a miniaturized high voltage power supply is being developed in coordination with these instrument concepts by A. Ruitberg of GSFC.

## 10 SOUNDING ROCKETS AND SUB-ORBITAL PROGRAMS

*Program Status.* R. Pfaff is the Project Scientist for NASA’s Sounding Rocket Program, described briefly here. NASA’s Sounding Rockets Program provides a cost effective, rapid means to carry out unique scientific experiments in space, as well as to test new flight instrumentation. Sounding rockets provide the only platforms with which scientists can carry out direct in-situ measurements of the mesosphere and lower ionosphere/thermosphere region (40-120 km) which is too low to be sampled by satellite-borne probes. Furthermore, they provide quick access to high altitudes where astronomy, planetary, and solar observations can be made of radiation at wavelengths absorbed by the Earth’s atmosphere, including emissions from objects close to the sun (e.g., comets, Venus, Mercury) which are precluded from observation by a “g-jitter” environment, ideal for a variety of microgravity experiments. Unique features of sounding rockets include their ability to gather data along vertical trajectories, their low vehicle speeds (compared to satellites) with long dwell times at apogee, the “targets” (e.g., thunderstorms, aurora, cusp, equatorial electrojet, etc.) when conditions are optimum, including operations at remote launch sites, the recovery and re-flight of instruments and payloads, and the acceptance of a greater degree of risk which helps maintain the low cost aspect of the program. Sounding rockets also provide invaluable tools for education and training. Over 350 Ph.D.’s have been awarded to date as part of NASA’s sounding rocket program. Missions are selected each year based on peer-reviewed proposals selected by various science discipline offices at NASA Headquarters.

*Gravity Waves.* R. Goldberg led an international scientific team in the MaCWAVE Rocket Program, launched at Andoya Rocket Range (ARR) during July 2002 to study gravity wave effects on the polar summer mesosphere. Two sequences involving 9 rockets and 16 rockets were launched on July 1 and July 4, respectively. Alomar lidars and radars provided continuous ground-based sounding support during each sequence. The data from these measurements are expected to permit tracking of the waves from their tropospheric origin into the mesosphere, determine if the waves break there, and evaluate the energy dissipation produced by such breaking. This is the first phase of a two part program which will continue from ESRANGE in Sweden during January, 2003. The summer gravity waves were generated by convective disturbances such as frontal systems and electrical storms in the troposphere. In winter, they expect the waves to be generated orographically by the mountain range upwind of the rocket range. Analysis and inter-

pretation of data from the related 1999 DROPPS program, also conducted at ARR, continues. New results on electric fields in noctilucent clouds and the particle environment in PMSE regions are in preparation for submission to JGR.

*ALTUS Uninhabited Aeronautical Vehicle (UAV).* M. Desch, W. Farrell, R. Goldberg, and J. Hauser were part of a team selected to conduct flights on the ALTUS UAV during Summer 2002. The flights occurred from the Naval Air Station in Key West, Florida. This was a team effort with MSFC, R. Blakeslee, Principal Investigator. The payload was designed to measure the electromagnetic energy generated in the upward direction above thunderstorms. During August 2002, the UAV accumulated over 40 hours of flying time above 40K feet, with numerous passes over active electrical storms.

*Nightglow.* LEP investigators (W. Farrell, J. Houser) placed a VLF lightning detection system on the Nightglow long range balloon mission to be launched in December 02 from Australia. Nightglow is a GSFC/Laboratory for High Energy Physics investigation to examine the near-UV background light in the atmosphere for the planned NASA OWL ultra-high-energy cosmic ray experiment. The RF lightning sensor provided by LEP is used to discriminate lightning-related UV brightenings from other transient phenomena.

## 11 FUTURE MISSIONS

### 11.1 Messenger

Fabrication of the spacecraft and science instruments for the Discovery Messenger mission has begun. The purpose of this mission is to collect global information on the surface, interior, exosphere and magnetosphere of Mercury. Launch will be in 2004. Two fly-bys of Mercury will be executed prior to orbital insertion in 2009. The Principal Investigator is S. Solomon of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The lead institution for the spacecraft and mission operations will be the JHU/APL. Members of the Laboratory are Co-investigators, Instrument Scientists, and Associate Team Members as part of the geochemistry team that will use data from the x-ray, gamma-ray, and neutron spectrometers to determine the surface composition of Mercury.

LEP scientists will be responsible for the vector magnetometer and the investigation of the planetary magnetic field and the magnetic structure of Mercury's magnetosphere. The LEP magnetic fields co-investigators are M. Acuña and J.A. Slavin. Messenger will go into orbit about Mercury in 2009 following two earlier fly-by encounters.

### 11.2 Time History of Events and Macroscale Interactions during Substorms (THEMIS)

D. Sibeck is a Co-investigator on the THEMIS Medium Explorer (MIDEX) mission which NASA has selected for Phase A Concept study. The primary objective of

THEMIS will be to elucidate which magnetotail process is responsible for substorm onset at the region where substorm auroras map ( $\sim 10R_e$ ): (i) a local disruption of the plasma sheet current or (ii) that current's interaction with the rapid influx of plasma emanating from lobe flux annihilation at  $\sim 25 R_e$ . THEMIS's five identical probes measure particles and fields on orbits which optimize tail-aligned conjunctions over North America while ground observatories time auroral breakup onset. Three inner probes at  $\sim 10 R_E$  monitor current disruption onset, while two outer probes at 20 and 30  $R_e$  remotely monitor plasma acceleration due to lobe flux dissipation. D. Sibeck will serve as Project Scientist at GSFC if the mission is selected for flight.

### 11.3 Living with a Star (LWS)

*Sentinels.* The goal of the LWS Sentinel element is to understand the fundamental physics connecting solar phenomena to geoeffective events. The pre-formulation team has completed its report recommending a mission composed of 4 inner heliospheric mappers and a solar far side observatory. NASA Headquarters has initiated international negotiations to explore other possibilities. The Heliospheric Strategy panel has been formed to review all of the scientific objectives and available opportunities and make recommendations to NASA Headquarters. The Sentinels are expected to be launched no earlier than 2009. A. Szabo is the Sentinels Project Scientist.

*Geospace.* A Geospace Mission Definition Team composed of university, industrial, and government laboratory scientists has completed a report describing a program of targeted basic research aimed at understanding and characterizing the effect of solar variability on those geospace phenomena that most affect life and society. Within a more comprehensive program it describes a set of flight missions whose specific objectives are to (a) characterize and understand the acceleration, global distribution and variability of radiation belt electrons and ions that produce the harsh environment for spacecraft and humans in space, and (b) characterize and understand mid-latitude ionospheric variability and irregularities that affect communications, navigation and radar systems. An integral part of the program will be to develop models that incorporate the improved physical understanding of these two regions and subsequently lead to improved real-time specification of the space environment (nowcasting) and predict potentially hazardous space weather conditions (forecasting). The report contains priorities and options for space flights and will be the basis for an Announcement of Opportunity (AO) for the flight program. R. Hoffman is the Lead Geospace Definition Scientist and B. Giles the Deputy.

### 11.4 Frontier Mission

*Interstellar Probe.* NASA's Interstellar Probe will be the first spacecraft designed to explore the local interstellar medium and its interaction with our solar system. Its unique trajectory from Earth to  $\sim 200$  AU in

~15 years will enable the first comprehensive measurements of plasma, neutral atoms, magnetic fields, dust, energetic particles, cosmic rays, and infrared emission from the outer solar system, through the boundaries of the heliosphere and on into the local interstellar medium. The Integrated Science and Technology Definition Team (ISTDT) has established the primary science objectives for this mission along with the resulting mission requirements and recommended minimum scientific instrumentation. These results have been presented to NASA Headquarters for further consideration. A. Szabo is a member of the ISTDT.

### 11.5 New Millennium Program

*Solar Sail Demonstrator.* A team has been working in collaboration with JPL to design a mission to demonstrate the deployment and control of a solar sail powered craft. The GSFC concept incorporates a ~1600 m<sup>2</sup> solar sail powering a ~20 kg spacecraft in near-geosynchronous orbit. Besides proving the viability of the various solar sail technologies, this mission will also characterize the space environment of the sail end determine how much future science observations would be affected by this new mode of propulsion. The solar sail craft was one of the four finalist concepts proposed for the New Millennium Program ST-7 mission, however it was not selected. The same concept will be proposed for the ST-9 opportunity. A. Szabo is a member of the pre-phase A solar sail proposal development team.

*New Millennium Program/ST-5 Mission* The New Millennium Program's Fifth Space Technology Mission, ST-5, will launch three small, ~ 25 kg, satellites into geosynchronous transfer orbit in late 2004 or early 2005. Their objective is to provide flight validation for a dozen new technologies critical for the future deployment and operation of constellations of small satellites. ST-5 will also test deployment and operations strategies necessary to make future "constellation-class" science missions economically viable. In order to validate the suitability of these small spacecraft as platforms for particles and fields measurements and to exercise the mission's autonomous operations capabilities, the ST-5 spacecraft will each carry a miniaturized magnetometer. ST-5 successfully completed its Critical Design Review in July and fabrication has commenced. J.A. Slavin is the ST-5 Project Scientist and Dr. G. Le leads the science validation portion of the mission.

### 11.6 Triana

*Solar Wind Plasma and Magnetic Field Investigation (PlasMag).* The Triana Earth imaging mission will include a combined high-time resolution magnetometer and plasma instrument to study the solar wind and to provide real-time space weather data. The Triana spacecraft is completely assembled and tested waiting for a launch opportunity. K. Ogilvie is the Principal Investigator of the PlasMag development team and the lead for the electron electrostatic analyzer. A.J. Lazarus (MIT) is the lead for the Faraday Cup positive ion subsystem

and M. Acuña for the magnetometer. A. Szabo is responsible for the ground data system.

### 11.7 Magnetospheric MultiScale (MMS) Mission

S. Curtis continues as Project Scientist for the MMS mission. Work has been focused on the interspacecraft ranging system, a critical component of this mission whose architecture is driven by in-situ measurements performed simultaneously by the four identical spacecraft. The onboard ranging system will enable the exploration of processes on scales in the magnetosphere that have not been accessible by previous missions. The increase in resolution will be almost two orders of magnitude better than previously obtained and will enable the study of magnetospheric dynamics on some of the smallest scales (electron inertial lengths). Work is also underway on a science staffing plan for the direction of the MMS mission's execution. The unprecedented complexity and orbital choreography require new approaches to scientific oversight. Extensive use will be made of lessons learned from the European Space Agency's Cluster II mission.

### 11.8 Autonomous Nano Technology Swarm (ANTS)

To date most constellation class mission designs have focused on large numbers of non-interacting, non-autonomous spacecraft. This mission architecture may be appropriate for a limited class of future missions, however many will require interacting, autonomous swarms of spacecraft to enable them. ANTS represents an attempt to develop precisely the structure needed for this latter class of missions. The ANTS effort under the direction of the Principal Investigator, S. Curtis, has focused on the software structure needed to enable a synthetic neural system which would provide the basis for the level of artificial intelligence required for interacting, autonomous swarms of spacecraft. The resulting self similar, hierarchical neural software system extends through the entire spacecraft. The highest nodes of the system are the individual spacecraft. Work is starting on the development of detailed elements of the neural software system in collaboration with the GSFC Engineering Directorate. The concept has proven a powerful tool in acquainting college and high school students with artificial intelligence concepts in the context of spacecraft autonomy and swarm behavior. It is anticipated that robust partnerships with those groups within NASA that are presently focussed on artificial intelligence with open a new era in the development of mission oriented artificial intelligence based on the ANTS paradigm.

### 11.9 Space Technology-8 (ST-8)

As the result of a partnering activity between S. Curtis, the GSFC Engineering Directorate, and JPL, plans are proceeding for the use of the ST-8, a part of a series of NASA technology demonstration missions, as an opportunity to testbed a concept for using Commercial

Off-The-Shelf (COTS) computers in space. If successful, this activity would result in much greater computational bandwidth in space. This would provide the hardware necessary conditions for the construction of greater autonomy for spacecraft and the instruments they carry. The proposal activity is a direct outgrowth of work performed by a group lead by S. Curtis as a Principal Investigator in the NASA Remote Exploration and Experimentation Program, a part of the U.S. Government's High Performance Computing Initiative.

#### 11.10 Multispectral Earth Radiated Light Imaging Network (MERLIN)

Initial planning is underway for a MDEX mission proposal that would provide for the first time continuous, simultaneous observations of both the northern and southern terrestrial auroral zones, as well as radiating processes at intermediate latitudes. The MERLIN would be a joint APL-GSFC partnership under the direction of S. Curtis as Principal Investigator. The auroral zone imaging will provide a pathway for a unique continuous tomographic view of magnetospheric dynamics and hence space weather. The resulting data will provide constraints on the next generation of global magnetospheric codes for which S. Curtis has had direct roles in as a Principal Investigator, Program Scientist, and Project Scientist. The intermediate latitude measurements will provide a detailed continuous global picture of ionospheric and upper atmospheric dynamics. These data will constrain the next generation of upper atmosphere global circulation models, for which there are now several attempts underway to use them as inner boundaries for the magnetospheric global simulation codes.

#### 11.11 Mars-Polar Scout Mission

LEP investigators (W. Farrell, D. Connerney, M. Acuña, and J. Trombka) were involved in the formulation and development of Mars-Polar, a mission proposal submitted to the Mars Exploration Program's Scout Initiative. The proposal features an astrobiology suite of instruments on a solar-heated Montgolfiere balloon to circumnavigate the north pole of Mars in 2008. The group provided science rationale and the provision of hardware including a radio sounder, magnetometer and neutron spectrometer. A decision on an award will be made in late 2002.

#### 11.12 Magnetospheric Constellation Mission (MCM)

T. Moore continued as Project Study Scientist for the definition of this Solar Terrestrial Probe mission. P. Buchanan joined as the Project Formulation Manager. The final report of the STDT appeared in early June 2001, and has been distributed in various venues and via the WWW at <http://stp.gsfc.nasa.gov> during FY2002. Attention is currently focusing on overall mission architecture and cost, with IMDC runs scheduled for the spacecrafts in September 2002, and for the dispenser ship in November 2002. A top priority is to bring the expe-

rience with the ST-5 mission to bear on the design and costing of the MCM, and to extend the traditional costing approach to include industry experience with small production runs of other technological systems, via the PRICE model.

#### 11.13 VESPER

*Simulated Neutral Atom Emissions from Venus.* One of the winning tactics of the re-proposed VESPER mission is the addition of an IMAGE/LENA-type instrument to the orbiter. LENA imaging has emerged as a promising new tool to study the interplanetary medium and its interaction with the Earth's magnetosphere, in addition to the ionospheric heating and outflow that result from this interaction. Venus, unlike the Earth, has no intrinsic magnetic field so the solar wind directly interacts with its atmosphere. The interaction processes control escaping atoms and thus play an important role in the evolution of the atmosphere. In order to determine the applicability of LENA imaging technique to Venus, ENA emissions from the planet have been calculated by M.-C. Fok using the global MHD model of T. Tanaka and colleagues. Preliminary analysis shows that the simulated ENA emissions suffice to probe the Venus plasma environment and its interaction with the solar wind.

### 12 EDUCATIONAL OUTREACH AND TECHNOLOGY TRANSFER

*Outreach Talk.* In mid-December 2001, R. Lepping was invited to give a "Teacher's Thursday Talk" at the Maryland Science Center on two unique missions: the out-of-the ecliptic Ulysses mission and the new Genesis solar wind composition mission. The Genesis spacecraft was launched last year and started collecting solar wind particles on December 3, 2002, only about one week before the talk. It will orbit the L1 point and in 2004, after about 30 months, be commanded to return to Earth for a helicopter retrieval of the science canisters of collected material for laboratory study.

*Laboratory Education/Outreach Website Development.* D. Taggart, M. Collier, and R. Lepping are leading an effort, joined by various members of the Laboratory, to continue the development of the Education/Outreach Website. The site attempts to appeal to a broad audience, but targets high school students in particular and highlights the scope of the Laboratory's research and its collaborations. The site has increased the number of major search engines from which it can be accessed. A new page, called Current Events, has been added which highlights science events in the news that pertain to the Laboratory's areas of interest. A few new space science tutorials have been added. The Website's "publication list" continues to grow as more books of particular interest in these fields are published and reviewed by the staff.

*Visiting Summer High School Student.* As part of the National Space Club Scholars program, a gifted high school student (T. Ferguson) helped R. Lepping and D.

Berdichevsky analyze the solar wind velocity observed in interplanetary magnetic clouds. During six weeks starting in late June 2002, the student developed various IDL programs to understand the relationship between velocity profiles and magnetic cloud expansion. This feature led to the discovery that clouds primarily expand along the XGSE axis rather than in the directions perpendicular to the ecliptic plane. The student also contributed to the development of various parts of the Lab's Education and Public Outreach website, emphasizing "Student Activities."

*Visual System for Browsing, Analysis, and Retrieval of Data (ViSBARD).* Visbard is a precursor to a Space Physics Virtual Observatory (SPVO). D.A. Roberts, in collaboration with commercial software developers and other GSFC personnel (including M.L. Goldstein and T.E. Moore) have produced a new way of visualizing data that makes it possible to view simultaneously a large number of measured time series on the orbits of a large number of spacecraft. As currently configured the software is capable of reading data (ASCII/CDF) for many existing missions. ViSBARD can be extended to interpret any number of ASCII and CDF formats through XML definitions, and they intend to add other formats. Each measurement is presented by a glyph (symbol or vector) at each point in time and at the position it was measured in the 3-D space. The ecliptic plane and, if appropriate, magnetospheric surfaces are presented to provide context. The software allows scrolling and zooming in time; the usual pan, zoom, and rotate in space; scaling of the data variables; a choice of color palettes; and 2-D graphs that scroll and scale in concert with the 3-D representation to aid the interpretation of the 3-D visualization. We plan to support stereo viewing. ViSBARD can display the SSC database that gives orbits of most currently operating SEC-related satellites as well as the COHOWeb database that contains most of the hourly averages of interplanetary spacecraft. A 'combine' tool allows the user to assemble, e.g., plasma, magnetic field, and orbit data from separate files for a single satellite into one data set at any desired resolution. ASCII output makes it possible to save subsets or combined datasets for later or other use. Future plans include linking to distributed databases, as well as to solar images (ultimately via the Virtual Solar Observatory) and magnetospheric and ionospheric images. We will also include model output in the visualization. The project will provide open-source software to encourage contributions from the space physics community.

*Mentoring a Summer Student.* N. Gopalswamy mentored a Summer Intern, A. Williams, a computer science student from South Carolina State University. She participated in the Summer Institute in Engineering and Computer Applications (SIECA) program. The intern had the opportunity to learn about the Sun-Earth connections and how solar disturbances can affect the human society. She also helped the research activities of N. Gopalswamy by measuring the drift rates of interplanetary type II bursts detected by the Wind/WAVES

experiment to obtain the speed of shocks responsible for the type II bursts. The shock speeds were then compared with the speeds of coronal mass ejections observed by the SOHO mission's coronagraph.

*National Institute of Justice/NASA Dual Technology Program.* The National Institute of Justice (NIJ) and GSFC have teamed up in a dual technology program to explore the use of NASA developed technologies to help criminal justice agencies and professionals solve crimes. The objective of the program is to produce instruments and communication networks that have application in both NASA's space programs and in NIJ programs with state and local forensic laboratories. A working group of NASA scientists and law enforcement professionals has been established to develop and implement a feasibility demonstration program. Specifically, the group has focused its efforts on identifying gunpowder and primer residue, blood and semen at crime scenes. Non-destructive elemental composition identification methods are carried out using portable x-ray fluorescence systems. These systems are similar to those being developed for planetary exploration programs. A breadboard model of a portable x-ray fluorescence system has been constructed for these tests using room temperature Silicon and Cadmium/Zinc Telluride detectors. Preliminary tests have been completed with gunpowder residue (gsr), blood-spatter and semen samples. These results have been accepted for publication.

*Elementary School Collaboration.* P. Romani collaborated with teachers and their students at Glenarden Woods Elementary School in Glenarden, Maryland, and at Wildwood Elementary School in Amherst, Massachusetts, to duplicate Eratosthenes's measurement of the circumference of the Earth. Eratosthenes was a Greek who lived and experimented in Egypt in the Ptolemaic era. His determination of the Earth's circumference was within 15% of the modern day value. The experiment was a success and the three sixth grade students presented the results at the Spring AGU meeting in Washington, D.C.

*NASA Undergraduate Student Research Program (USRP).* As part of the NASA-USRP R. Cody served as mentor to a student from Lynchburg College, Lynchburg, Virginia. During the Fall 2001 session of USRP D.A. Dalton worked in the kinetics laboratory of the Astrochemistry Branch and made significant contributions to the research efforts. He returned to Lynchburg College for the Spring semester and received B.S. degrees in Physics and Chemistry in May 2002. He now has secured a position with a pharmaceutical company in Lynchburg.

*Various Activities.* T. Livengood has engaged in numerous classroom visits and public talks presenting planetary and space science to the public, including personal work done with the infrared heterodyne spectroscopy group at GSFC. J. Delgado continued his work in the heterodyne spectroscopy laboratory during the 2001-2002 academic year and the summer of 2002, assembling and testing laser systems and contributing to

development efforts for the HIPWAC instrument.

*Advisory Activities.* T. Kostiuik serves on the NASA Keck/Infrared Telescope Facility Management Operation Working Group (MOWG) and was a member of the National Science Foundation (NSF) Division of Astronomical Sciences Committee of Visitors, evaluating the NSF Division and its astronomical sciences program.

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